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INDUSTRIAL PROCESSES TO REDUCE GENERATION OF HAZARDOUS
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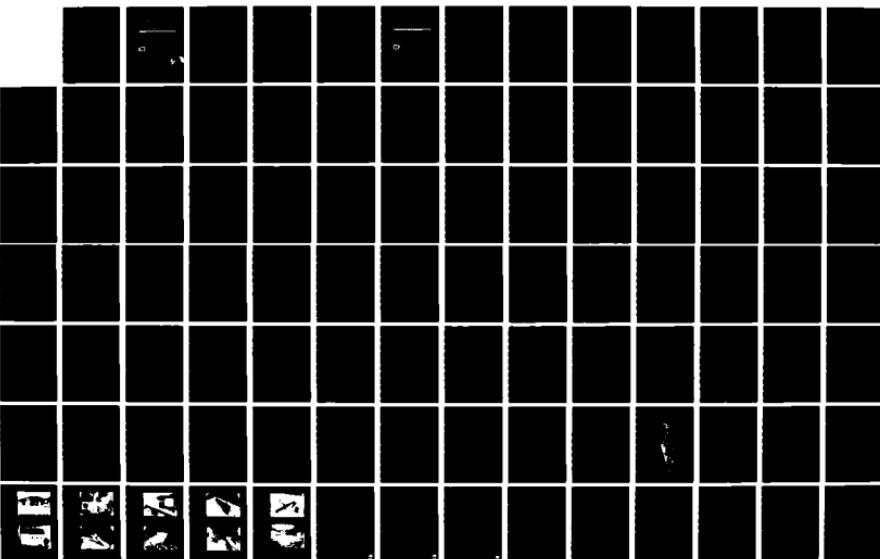
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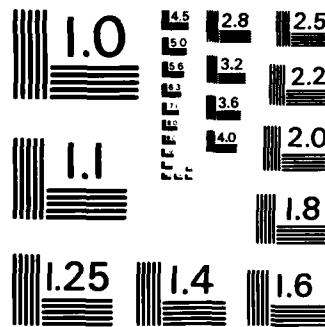
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INDUSTRIAL PROCESSES TO REDUCE GENERATION OF HAZARDOUS WASTE AT DOD FACILITIES

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PHASE 2 REPORT EVALUATION OF 18 CASE STUDIES

prepared for the
DOD ENVIRONMENTAL LEADERSHIP PROJECT
Washington, D.C.

and
U.S. ARMY CORPS OF ENGINEERS
Huntsville, Alabama

author
T.E. Higgins

CH2MHILL
July 1985

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This report was prepared by CH2M HILL, Inc., Reston, Virginia, under Contract Number DAC A87-84-C-0076, August 17, 1984, for the Defense Environmental Leadership Project (DELP) and the U.S. Army Corps of Engineers (COE). Dr. Richard Boubel was the Project Officer for DELP and Mr. Stan Lee was the COE Project Officer. Dr. Thomas E. Higgins was Project Manager for CH2M HILL and was principal author. Major contributions to this report were made by Daniel Bostrom, J. Kendall Cable, Thomas R. Card, Drew P. Desher, R. Benson Fergus, and Brian R. Marshall, all of CH2M HILL.

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The report, which covers the second phase of the project, evaluates 18 case studies of industrial process modifications that were recommended for further evaluation in Phase 1 of the project. From these 18 case studies, three are recommended as "Projects of Excellence" to be promoted during Phase 3 to encourage similar efforts elsewhere in the armed services.			
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reuse, reclaim, or recycle resources in order to conserve raw materials. Many studies of DOD facilities have recommended industrial process modifications that would reduce wastes generated at the source, rather than concentrating efforts on end-of-pipe treatment facilities. Many of these modifications, some of which feature excellent cost/benefit ratios, have been successfully implemented; some, however, have not. This project was performed to determine the factors that contributed to success or lack of success of these modifications. Therefore, the methods (such as the use of incentives) and management practices employed to successfully implement a given modification are important factors in the evaluation of the case studies examined in this report. The case studies also were evaluated on the basis of technical practicality, cost, energy consumption, and program monitoring and auditing.

INDUSTRIAL PROCESSES TO REDUCE GENERATION OF HAZARDOUS WASTE AT DOD FACILITIES

PHASE 2 REPORT EVALUATION OF 18 CASE STUDIES



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CONTENTS

	<u>Page</u>
SUMMARY	1
1. INTRODUCTION	1-1
1.1 Background	1-1
1.2 Project Objectives	1-2
1.3 Sources of the Cases Studied	1-3
2. SCOPE OF WORK	2-1
3. SOLVENT-RELATED MODIFICATIONS	3-1
3.1 Descriptions of Solvent Waste Sources	3-1
3.1.1 Paint Stripping	3-1
3.1.2 Painting	3-4
3.1.3 Solvent Cleaning and Degreasing	3-6
3.2 Magnitude of the Problem	3-8
3.2.1 Solvent-Related Hazardous Wastes--Environmental Compliance	3-8
3.2.2 Problem Definition--Paint Stripping and Painting	3-12
3.2.3 Problem Definition--Solvent Cleaning and Degreasing	3-13
3.3 Technologies Available to Reduce Solvent-Related Hazardous Waste	3-13
3.3.1 Paint Stripping Modifications	3-13
3.3.2 Painting Modifications	3-30
3.3.3 Solvent Recovery and Reuse	3-26
3.4 Solvent Case Studies	3-29
3.4.1 Plastic Media Paint Stripping at Hill AFB	3-29
3.4.2 Dry Media Paint Stripping at Pensacola NARF	3-48

CONTENTS (continued)

	<u>Page</u>
3.4.3 Water-Based Primer Painting at Pensacola NARF	3-52
3.4.4 Spray Painting at Lockheed-Georgia Company	3-55
3.4.5 Electrostatic Dry Powder Painting at Hughes Missile Division	3-58
3.4.6 Solvent Recycle Program at Robins AFB	3-60
3.4.7 Paint Solvent Recycling at Norfolk NSY	3-63
3.4.8 Stoddard Solvent Recycling at Tyndall AFB	3-65
3.4.9 Heptane Recovery at Norfolk NARF	3-67
3.4.10 TCE Recycling at Anniston Army Depot	3-69
3.5 Solvent Recommendations	3-70
3.5.1 Paint Stripping	3-70
3.5.2 Painting	3-71
3.5.3 Solvent Cleaning and Degreasing	3-72
3.6 Solvent References	3-72
4. METAL PLATING RELATED MODIFICATIONS	4-1
4.1 Description of Metal Plating	4-1
4.2 Magnitude of the Problem	4-2
4.2.1 Plating Wastes--Environmental Regulations	4-2
4.2.2 Problem Definition--Metal Plating	4-6
4.3 Technologies Available to Reduce Hazardous Wastes from Metal Plating	4-10

CONTENTS (continued)

	<u>Page</u>
4.3.1 Housekeeping Practices	4-10
4.3.2 Drag-Out Reduction	4-11
4.3.3 Rinsewater Modifications	4-11
4.3.4 Chemical Recovery Processes	4-17
4.3.5 Material Substitution	4-28
4.4 Plating Case Studies	4-31
4.4.1 Ion Vapor Deposition of Aluminum at North Island NARF	4-31
4.4.2 Non-Cyanide Cadmium Plating at Lockheed-Georgia Co.	4-34
4.4.3 Innovative Hard Chromium Plating at Pensacola NARF	4-35
4.4.4 LICON Chromium Recovery at Charleston NSY	4-50
4.4.5 Plating System at Anniston Army Depot	4-58
4.4.6 Sulfide Plating Wastewater Treatment at Tobyhanna Army Depot	4-60
4.5 Plating Recommendations	4-67
4.6 Plating References	4-69
5. VEHICLE WASHRACKS	5-1
5.1 Process Description	5-1
5.2 Magnitude of the Problem	5-2
5.3 Technologies Available to Reduce Hazardous Wastes From Washrack Operations	5-5
5.4 Vehicle Washrack Case Studies	5-7
5.4.1 Vehicle Washrack at Fort Polk, Louisiana	5-7

CONTENTS (continued)

	<u>Page</u>
5.4.2 Vehicle Washrack at Fort Lewis, Washington	5-13
5.5 Washrack Recommendations	5-17
5.6 Washrack References	5-19
6. CONCLUSIONS AND RECOMMENDATIONS	6-1
6.1 Conclusions	6-1
6.2 Selection Criteria for Projects of Excellence	6-2
6.3 Recommendations	6-5
6.3.1 Evaluation and Recommendation of Projects of Excellence	6-5
6.3.2 General Recommendations	6-7

WDR111/013

TABLES

		<u>Page</u>
1	Summary of Case Study Evaluations	18
3-1	Paint Strippers and Corresponding Paint Systems	3-3
3-2	Paint Stripping Wastewater Characteristics	3-2
3-3	Applications of Plastic Media Blast Paint Stripping	3-16
3-4	Annual Savings Comparison for All DOD Facilities--Preliminary Estimate	3-17
3-5	Comparison of Solvent Painting to Powder Painting	3-22
3-6	Solvent Data Sheet	3-27
3-7	Suppliers of Self-Contained Distillation Apparatus	3-28
3-8	Savings Comparison--Plastic Media Versus Solvent Paint Stripping	3-32
3-9	Production Comparisons at Hill AFB	3-34
3-10	Explosive Properties of Dry Organic Media	3-51
3-11	Alternative Painting Technologies	3-71
4-1	Hazardous Waste from Nonspecific Sources	4-3
4-2	EPA Metal Finishing Subcategory Pretreatment Standards for Existing Sources	4-5
4-3	Capital Costs, Innovative Chromium Plating System	4-43
4-4	Charleston NSY Hard Chrome Plating Operating Conditions	4-51
4-5	Relative Costs of LICON Unit for Chromium Recovery	4-56
4-6	Relative Costs of Using LICON Cation Exchange for Chromium Recovery from Rinsewater	4-58

TABLES (Continued)

		<u>Page</u>
4-7	Tobyhanna Army Depot Waste and Treated Effluent Analysis	4-64
4-8	Treatment Plant Installation Costs	4-64
4-9	Plating Wastewater Flow Data	4-65
5-1	Effluent Quality Criteria	5-6
5-2	Summary of Problems and Recommended Solutions for Design, Construction, and Operation of CVWFs and Vehicle Maintenance Facilities	5-18
6-1	Evaluation of Case Studies	6-6

WDR111/030

FIGURES

		<u>Page</u>
3-1	Plastic Media Paint Stripping Hangar, Hill Air Force Base	3-36
3-2	Building 223, Hill AFB PRAM Plastic Media Paint Stripping Facility	3-40
3-3	Equipment Room	3-40
3-4	Plastic Media Stripping of F-4 Aircraft (Floor level view)	3-41
3-5	Plastic Media Stripping of F-4 Aircraft (Viewed from above)	3-41
3-6	Plastic Media Stripping Peeling Paint from Anodized Aluminum Surface	3-42
3-7	F-4 Aircraft Component Mounted for Stripping	3-42
3-8	F-4 Aircraft Component Stripping Completed (Angle 1)	3-43
3-9	F-4 Aircraft Component Stripping Completed (Angle 2)	3-43
3-10	F-4 Aircraft Component Stripping Completed (Angle 3)	3-44
3-11	F-4 Aircraft Stripped by Conventional Solvent Methods	3-44
3-12	Layouts of Single and Two-Unit Plastic Media Blast Booths	3-45
3-13	Layout of Four-Unit Blast Booth (Double tandem modules)	3-46
3-14	Layout of Six-Unit Blast Booth (Multiple modules)	3-47
4-1	Typical Treatment of Plating Wastewater	4-7
4-2	Drag-out Recovery Devices	4-12
4-3	Improved Rinse Tank Design	4-14
4-4	Three-Stage Countercurrent Rinse System	4-16
4-5	Zero Discharge Evaporation System	4-19

Anniston Army Depot (3.4.10), located in Anniston, Alabama, utilizes small distillation units that are individually attached to 15 vapor degreasers for the reclamation of trichloroethylene (TCE). The stills operate continuously when the vapor degreasers are in operation, normally 40 hr/week. Dirty solvent is fed from a degreaser boiling sump through a water separator to the recovery still. The steam-heated stills have the capacity to recycle 20 gal/hr of TCE. The still bottoms, which contain TCE, oils, greases, and dirt, are automatically discharged to holding drums and then disposed of as a hazardous waste. Due to recycling, vapor degreaser baths never have to be dumped and disposed of. Losses of TCE are only due to drag-out, evaporation, and waste still bottoms. Twice a year during shutdown, the vapor degreasers and stills are taken out of service for cleaning and general maintenance.

Production personnel have been receptive to the stills because TCE baths are kept clean and consequently product quality is improved. The distillation units are also simple to operate and maintain.

METAL PLATING

"Plating" is defined as the deposition of a thin layer of metal on the surface of a basis metal for the purpose of changing the properties of the basis metal. These modifications may be to improve the appearance (decorative plating), to increase resistance to corrosion, or to improve engineering properties (hardness, durability, solderability, or frictional characteristics) of the basis metal. The principal metals plated at military facilities are chromium and cadmium.

Chromium is used principally in the remanufacturing of worn parts whose replacement with new parts would be infeasible because of their unique design. Remanufacturing consists of stripping a portion of the old plate, overplating with a thick layer of chromium (hard chrome plating), and machining back to original specifications. Parts are typically plated for longer than 24 hours, to achieve the required thickness of chromium.

Sacrificial cadmium coatings are normally applied to protect the basis metal, typically iron or steel. A thin surface coating is normally applied to provide corrosion protection, improve wear or erosion resistance, reduce friction, or for decorative purposes. These coatings are significantly thinner than hard chrome plating, and are applied in minutes rather than the hours or days required for hard chrome plating.

recycling team so that waste solvents can be segregated, labeled, analyzed, transported, and redistilled in an orderly and systematic fashion. In addition, proven distillation equipment was available and was relatively easy to operate and maintain. One major factor in the success of the Robins solvent recovery program has been the commitment of Mr. O. H. Carstarphen, the Solvent Reclamation Engineer. Through his perseverance, colleagues and management were convinced to supply equipment and manpower to set up and run the program.

In contrast to a centralized facility, Norfolk Naval Shipyard (3.4.7) in Norfolk, Virginia has installed a \$10,000 nonfractionating, batch still to recover waste solvents generated in the paint shop during cleaning operations. This small still, which has a capacity of 2 gal/hr, is used to recover methyl isobutyl ketone, MEK, epoxy thinners, and mineral spirits. Operators have the option to operate the still with or without a vacuum system depending upon the distillation temperature required. After a 15-minute startup period, the still runs without operator attention. Over 50 percent of the waste solvent is recovered at a cost of about \$0.15 per gallon.

The recovery process was successful at Norfolk because of the personal dedication of Mr. Jake Coulter, the Paint Shop Foreman, and the straightforward, uncomplicated operation of a technically innovative system.

Tyndall AFB (3.4.8) failed to economically recycle Stoddard solvent (PD-680) with a central vacuum still due to lack of waste solvent. The quantities were less than originally anticipated because many original users had switched to another solvent, because of difficulties with collection, storage, and transport of the waste solvent, and because of a reluctance to use recycled solvent. In addition, the facility had been set up as a research effort, without a strong commitment from base personnel and management.

Norfolk NARF (3.4.9) was unable to meet military specifications for heptane recovered with a batch still. The heptane, which was used as a calibrating fluid, failed to meet specifications because the waste heptane was stored in a large underground storage tank into which other solvent waste lines drained. The non-fractionating still was not equipped to separate a mixture of solvents. In order for solvent recycle to be successful, individual solvents need to be carefully segregated. The still was given to the facility by higher command with instructions to use it for solvent recycle. Local personnel were not involved in this decision process, and a poor choice of application was made.

The main advantage of operating a large centralized facility is that capital costs can be recovered quickly due to economies of scale. A centralized facility can redistill large quantities of various types of solvents. Since many different types of solvents are recycled, great care must be taken with waste segregation and sample analysis. One disadvantage of centralized reclamation is that solvents must be transported to and from the point of use.

Decentralized facilities are sometimes preferable because the waste generator has total control over the recycling operation. Since only a few types of solvents are being redistilled at the small facilities, laboratory analysis of waste solvents is often not required. Labor-intensive transportation and segregation activities are also eliminated.

A centralized facility is dependent on a dedicated individual to initiate and supervise operation of the system and an enthusiastic staff dedicated solely to solvent collection, analysis, recycling, and distribution. Decentralized facilities require the conversion of more personnel (foreman and operators) to adopt solvent recovery as part as their routine.

Warner Robins AFB (3.4.6), located in Macon, Georgia, has operated a centralized batch, atmospheric still since August of 1982. The organic fluid recovery system consists of a single-stage batch still, a water separator, and an electrically powered steam generator. The still, which can operate up to a temperature of 300°F in the pot and can reclaim organic fluids at a rate of 55 gallons per hour, is used to reclaim trichloroethane, Freon-113, and isopropanol at recovery rates of 70 to 99 percent. From the initial startup to December 31, 1984, it was estimated that over \$230,000 was saved due to reduced need for virgin material and reduced hazardous waste disposal costs. It cost only \$13 per drum to reclaim the used chemicals, whereas disposal of the chemicals and repurchase of new materials would have cost from \$250 to \$500 per drum.

Robins AFB has been able to successfully recycle solvents in a large-scale operation because of careful waste segregation, storage, and transportation. Site managers are responsible for segregation and labeling of waste drums at 30 different collection areas. Before solvents are reclaimed, samples are analyzed to confirm the labeling. Samples are also analyzed after distillation to ensure that they meet appropriate specifications.

Solvent recycling has been successful at Robins AFB because of a strong commitment from management to reduce the quantities of waste solvents that must be disposed of. More importantly, production personnel have cooperated with the

RECYCLE OF SOLVENTS

Solvents and other organic fluids are used at virtually every military facility. They are used for cleaning, degreasing, paint booth cleaning, instrument calibration, refrigeration, and machining operations. Trichloroethylene, 1,1,1-trichloroethane, and perchloroethylene are used in vapor degreasers, and mineral spirits, such as Stoddard solvent and Varsol, are used in cold cleaning baths. Alcohols and Freon are commonly used for metal preparation and precision cleaning of electronics equipment. Solvents are also used in painting operations. Methylene chloride is commonly used to strip paint and carbon from metal surfaces, and toluene is commonly used to thin solvent-based paints. Volatile solvents, such as methyl ethyl ketone (MEK) and xylene, are used to clean painting equipment.

Disposal costs for waste solvents can exceed \$1,000 per drum. This cost is expected to increase substantially in the future because of RCRA regulations that are scheduled to ban the land disposal of liquid hazardous wastes. When waste solvents are disposed of, fresh solvents must be purchased, usually at a cost that exceeds the cost of waste disposal. Therefore, recycling of waste solvents can result in savings of hundreds of dollars per drum.

There is great potential for reducing the quantities of solvents and related by-products generated at DOD industrial facilities. Solvents and other organic fluids are most frequently reclaimed by batch distillation. Batch distillation systems typically consist of a still pot, a heat source, and a condenser. The waste organic mixture is loaded into the still pot, and heat is applied to the contents, causing the mixture to boil; organic vapors separate from the waste mixture and pass overhead to the condenser. Cleaned organic fluid is then collected for reuse and still bottoms are disposed of as hazardous waste.

An atmospheric still can reclaim organic solvents that have boiling points less than 325°F. By adding vacuum, a distillation unit can be used to recover organic fluids which have atmospheric boiling points up to 500°F, while maintaining a 300°F limit in the still's pot. A still is usually heated by electricity or indirectly by steam generated by an electrically heated boiler.

Waste solvents can be either collected and transported to a centralized distillation facility for recovery or recycled at the point of use. DOD facilities have been successful with both approaches. Regardless of where the distillation occurs, it is critical that waste solvents be properly segregated and stored so that mixing of various solvents and impurities does not occur.

Robotics was also investigated by Lockheed in an attempt to improve product quality and production efficiency and to reduce paint overspray. The robot had the capability to paint an 8-foot by 6-foot rectangular area and could be used for both normal spray painting and electrostatic painting. Usage was discontinued, however, because of difficulty in spraying the irregularly shaped aircraft parts. The use of robotics is better suited for private sector industries which feature mass production of vehicles and parts. Most military manufacturing and rework facilities strip and paint an extremely diverse number of parts and materials. These facilities are often not amenable to computerized control robotics since there is a wide range of variables (part sizes, shapes, materials, quantities, etc.) that can change during the course of a day.

Dry powder coating (or painting) is based upon the deposition of special heat-fusible plastic powders onto metallic substrates. Powder coatings are applied by powder spray guns, fluidized bed methods, electrostatic deposition, or plasma spray techniques. Typical advantages of powder coating techniques are that solvent usage is eliminated, paint spray is often minimized, and the spray can be recycled. There is virtually no hazardous waste problem.

At Air Force Plant 44, located in Tucson, Arizona, Hughes Aircraft (3.4.5) uses electrostatic dry powder painting to coat the interior of the fuselage section of the Phoenix Missile. Electrostatic deposition of dry solids works by attraction between charged, dry paint particles and an electrically grounded (negative) or positively charged bed. By spraying the charged coating onto an oppositely charged substrate, coatings as thin as one mil (0.001 inch) can be applied. Hughes Aircraft has found that this technique is superior to the previous wet spray application because of better coverage on hard-to-reach surfaces. Fewer coatings are required, less equipment maintenance is needed, and hazardous waste generation is reduced. Consequently, significant cost reductions have been achieved. It has been estimated that powder coatings could be applied for approximately one-third the cost of conventional wet paint spraying, due in large part to the reduced number of coatings required. The technique, however, requires highly skilled operators; hence, extensive training is necessary.

The process modification was successful because it improved both the production rate and quality, decreased manpower requirements, and consequently decreased costs. As with other case studies, an improvement in production became the primary motivation behind implementing the process modification. The subsequent reduction in hazardous waste generation became a secondary benefit.

In order to meet strict VOC air emission standards, many military and military contractor facilities in California have recently switched to a water-reducible, amine-cured epoxy primer which contains low concentrations of VOC compliance solvents. At application, the waterborne coating typically has a VOC concentration of less than 340 g/L, or one-fourth that of conventional solvent-based primers. Another advantage of water-based paints is that cleaning can usually be performed using hot water and/or alcohol. Since solvents are not required for cleanup operations, solvent use and solvent waste production are substantially reduced.

Recently, Pensacola and Jacksonville NARFs (3.4.3) partially switched from conventional solvent primers to waterborne primers. Unlike military facilities in California, which has strict VOC emission regulations, the Florida NARFs implemented the material substitution in order to improve product quality. In the past, approximately 20 percent of parts painted with solvent-based primers were rejected and had to be repainted. This rejection rate has been reduced to 2 percent with the new water-reducible primer.

There are a few disadvantages of the waterborne primers. For example, they are slower to dry than solvent-based paints, and some believe that they do not provide the same overall corrosion protection. Water-based primers also do not adhere well to oily surfaces. Nevertheless, personnel at Pensacola and Jacksonville NARFs have found that in most of their applications, water-based primers are superior overall due to ease of application, decrease in overspray, lower rejection rate, and ease of cleanup.

Lockheed-Georgia Company (3.4.4) has investigated various painting modifications at Air Force Plant 6 to reduce the quantities of paint thinner solvent (i.e., toluene) and paint used at the facility, and also to reduce the generation of solvent wastewaters and paint sludge. Solvent usage, and hence solvent waste, was reduced by increasing the amount of zinc-chromate solids in the primer during a test period. Lockheed found that it was more difficult to evenly apply the primer and control paint thickness due to rapid buildup of paint solids, especially on irregularly shaped parts. This modification was therefore abandoned in favor of the existing solvent-based, low solids (20-22 percent) primer.

Lockheed improved their painting techniques by installing a modern conveyor system in the paint line. Small aircraft parts can be plated, painted twice, and oven cured--if necessary--without being touched by human hands. Using the conveyor system, product quality was improved and production rates were increased. Paint overspray was also reduced by retraining operators and inspectors on the proper paint thickness that should be used.

Personnel at Hill AFB and Pensacola NARF initially implemented the process modification because of a desire to improve working conditions and to reduce the generation of hazardous waste. They subsequently found that plastic media stripping improved product quality and decreased production costs, since manpower requirements were substantially reduced. The combination of reduced manpower and improved product quality have now replaced environmental and occupational health and safety benefits as the incentives to expand application of this new technology. The elimination of wastewater discharges has become a secondary benefit. The process is successfully being applied at both facilities because of strong support from management, engineering, and maintenance personnel, as well as the fact that the technology selected is appropriate to the skill levels of the personnel involved.

PAINTING

Painting is common to virtually all DOD industrial facilities. Paint coatings are applied to surfaces of military parts, vehicles, and structures for corrosion protection, camouflage, or aesthetic appeal. In conventional spray painting, paint is thinned with solvent and applied to surfaces in a wet form. Typically, low transfer efficiencies are realized--less than 50 percent of the paint solids used end up on the parts. Paint overspray is scrubbed from paint booth exhaust air by a water spray, and solvents are used to clean painting equipment. Spray booth sludges and waste solvents are collected for disposal as hazardous waste.

Most DOD spray painting is performed on Air Force and Navy aircraft. With thousands of military aircraft in service, a significant volume of paint and paint solvents is consumed every year, with a significant portion becoming hazardous waste.

Aircraft are typically coated with two layers of solvent-based paint. The primer is usually an epoxy polyamide compound, and the topcoat is usually an aliphatic polyurethane compound. The primary function of the primer is to promote adhesion of the polyurethane topcoat and to protect the aluminum substrate from corrosion. The topcoat serves as an additional corrosion protection layer.

Alternatives to conventional solvent-based spray painting have been approached by both improving painting techniques and developing processes which either reduce or eliminate solvent thinners in paint. Some of the most promising developments are: waterborne coatings, dry powder coatings, wet electrostatic painting, high-solids coatings, improved painting techniques, and robotics.

Hill AFB completely stripped an F-4 fighter plane in July of 1984. This test demonstrated that the process was much less labor-intensive and less occupationally hazardous than solvent stripping. The aircraft was completely stripped in 40 manhours, versus 340 manhours required for wet paint stripping. In addition, greater control in stripping was achieved, compared with wet paint stripping and sanding, resulting in reduced damage to underlying surfaces.

A full-size plastic bead blasting hangar has been constructed based on the prospect of reduced manpower requirements and favorable environmental impact. The hangar incorporates five blast positions and a live floor vacuum system to provide ventilation and dust removal, and a separation system for bead recovery and reuse. This hangar was used to blast strip an F-4 aircraft in an elapsed time of 5.4 hours.

The new hangar cost \$647,389 to purchase and install. Yearly savings are anticipated to be \$5,600,000, resulting in a 6-week payback period. DOD estimated that over \$100 million could be saved annually and that generation of millions of gallons of hazardous wastewaters per day could be avoided by switching to plastic media paint stripping at all facilities.

The Naval Air Rework Facility (NARF) in Pensacola, Florida (3.4.2) has successfully stripped paint from aircraft and helicopter parts using plastic media. Paint stripping of parts is currently being done in enclosed glove boxes and walk-in blast rooms. Pensacola's long-range plans involve converting two helicopter hangars to accommodate dry media stripping. These plans have been postponed pending resolution of OSHA regulations that prohibit people from working in rooms in which blasting is carried out with "organic" media. Concern was expressed that generation of dust may pose a possible explosion hazard.

There are two primary disadvantages of plastic media stripping. First, successful stripping requires that the plastic media be harder than the coat of paint. At Pensacola, aluminum surfaces coated with epoxy and urethane paints are presoftened with a stripping solvent, such as methylene chloride, and then allowed to dry prior to blasting. Bob Roberts noted that this use of solvents defeated the advantage of dry blasting and could not be carried out with a live floor bead recovery system. Secondly, stripping of thin-skin aluminum, magnesium, fiberglass, and other composite surfaces requires skilled operators. Operators must carefully set and control a myriad of variables (e.g., bead hardness, roughness, and size; motive air pressure; standoff distance; application angle; nozzle size; feed rate; etc.) so that surfaces are not damaged during stripping.

Conventional sand and glass bead blasting techniques have been used for paint and rust removal from metal surfaces. However, these paint removal techniques cannot be used in many military applications because the hard abrasive media can damage aluminum and fiberglass surfaces and delicate steel parts. In addition, sand and glass bead blasting produces a silicate dust that can cause respiratory ailments, such as silicosis. Soft vegetable media, such as walnut shells and rice hulls, have successfully been used to strip paint from metal surfaces. However, these materials are susceptible to biological growth during storage, are difficult to recycle, and rapidly degrade, producing large amounts of dust that can create an explosion hazard. The used media is mixed with the removed paint and must be disposed of as a hazardous waste.

In plastic media stripping, small, rough-edged plastic beads are air blasted at the painted surface, causing the coating to dislodge. The key parameter for successful use of plastic media blasting is hardness--the paint must be softer than the plastic media, which in turn must be softer than the underlying substrate. Through careful control of the size of the beads and the conditions of the process, the plastic media can be separated from the loosened paint particles and recycled. Generation of wet hazardous waste (solvents and paint sludge in water) is completely eliminated. A small volume of dry hazardous waste is produced due to stripping of the zinc chromate primer.

Hill Air Force Base (3.4.1)^a in Ogden, Utah, has been the lead military facility in the development and testing of plastic media blasting technology. The development of this process modification is a clear example of the key elements contributing to the successful implementation of a modification. Of prime importance is the fact that the process itself is simple. Conventional sand blasting equipment was adapted to include media recovery and separation from the waste paint chips and dust.

This modification was spearheaded by Mr. Robert Roberts, a staff member at Hill AFB who recognized the environmental disadvantages of the existing methods used for stripping planes. He tried many methods before discovering, developing, implementing, and promoting the dry plastic media method.

Initially the motivation was to develop a process to replace the existing wet solvent process, which was environmentally objectionable and presented occupational hazards. Following extensive testing on aircraft components to demonstrate the process's effectiveness and safety, personnel at

^aRefers to chapter, section, and subsection in this report.

stripping, solvent cleaning (i.e., removal of dirt, oils, greases, and corrosion products), metal plating, and painting.

During Phase 1 of the project, 40 cases were evaluated, 32 of which dealt with metal finishing operations. The remaining eight cases involved explosives manufacture, jet engine test cells, fire fighting training, fuel tank cleaning, and purchase and use specifications.

Sixteen of the cases were studied in more depth during Phase 2 of the project. In addition, two cases involving Army vehicle wash racks were added, to bring the total number of cases evaluated in Phase 2 to 18. Case studies from the three armed services were evaluated on the basis of costs, energy consumption, technical practicality, management, incentives, and program monitoring and auditing.

Of the 18 cases evaluated in Phase 2, three cases are recommended as Projects of Excellence to be showcased with employee briefing and training programs during Phase 3. One involved modifications to metal plating at Pensacola Naval Air Rework Facility, another involved paint stripping using plastic media blasting at Hill Air Force Base, and the third involved reducing solvent and oil pollution associated with vehicle washing and maintenance facilities at Fort Lewis Army Post.

PAINT STRIPPING

Paint stripping, in preparation for reconditioning and recoating, is performed at virtually every DOD industrial facility. Complete stripping is often necessary for new paint and electrocoatings to properly adhere to existing surfaces. In typical military paint stripping, sprays or baths containing acidic methylene chloride, phenolic, or hot alkaline sodium hydroxide solutions are employed to dissolve and loosen old paint. After scraping, the resulting solvent-paint mixture is washed away with large volumes of water, resulting in significant quantities of hazardous waste. For example, approximately 20,000 gallons of solvent-laden wastewater is generated for each fighter plane that is paint stripped. In addition, hard to remove paint is machine sanded, often resulting in some damage to the metal substrate. Wet paint stripping is labor intensive, dirty, and contributes a significant load to waste treatment facilities.

Several alternative paint stripping processes have been studied by private industry and the military. Among these are: dry media blasting, laser stripping, flash lamp stripping, water jet stripping, CO₂ pellet blasting, and cryogenics. The most promising technique is dry media blasting using a soft recoverable plastic media.

SUMMARY

This is the second report of a three-phase effort for the Defense Environmental Leadership Project (DELP), which is designed to encourage the development and implementation of industrial process modifications in U.S. Army, Navy, and Air Force facilities and thus reduce the amount of hazardous wastes generated by those facilities.

The report, which covers the second phase of the project, evaluates 18 case studies of industrial process modifications that were recommended for further evaluation in Phase 1 of the project. From these 18 case studies, three are recommended as "Projects of Excellence" to be promoted during Phase 3 to encourage similar efforts elsewhere in the armed services.

The project is in keeping with Department of Defense (DOD) policy memorandum DEQPPM 80-5, issued in May of 1980 and reaffirmed in August of 1980 by policy memorandum DEQPPM 80-8. That policy essentially is to limit hazardous wastes generated by the U.S. Army, Air Force, and Navy through alternative procurement and operating procedures and, where possible, to reuse, reclaim, or recycle resources in order to conserve raw materials. Many studies of DOD facilities have recommended industrial process modifications that would reduce wastes generated at the source, rather than concentrating efforts on end-of-pipe treatment facilities. Many of these modifications, some of which feature excellent cost/benefit ratios, have been successfully implemented; some, however, have not. This project was performed to determine the factors that contributed to success or lack of success of these modifications. Therefore, the methods (such as the use of incentives) and management practices employed to successfully implement a given modification are important factors in the evaluation of the case studies examined in this report. The case studies also were evaluated on the basis of technical practicality, cost, energy consumption, and program monitoring and auditing.

The contract instructed that the project concentrate on a few processes that generate the greatest proportion of DOD hazardous wastes. The project therefore focused on those processes that generate the principal hazardous wastes at DOD facilities: solvent wastes (painting, paint stripping, and cleaning) and toxic metal wastes (electroplating).

DOD operates industrial facilities to repair and recondition planes, helicopters, ships, tanks, and other vehicles and equipment. Metal finishing operations, which are performed at over 100 DOD industrial facilities, produce most of DOD's hazardous wastes. Metal finishing operations include: paint

Summary

FIGURES (Continued)

		<u>Page</u>
5-8	Staggered Pipes for Flexing Treads (Normally Submerged) Causes Most of Tread Cleaning	5-12
5-9	Central Vehicle Wash Stands at Fort Lewis	5-15
5-10	Exterior Wash Stands at Fort Lewis	5-15
5-11	Covered Scheduled Maintenance Facility at Fort Lewis	5-16
5-12	Hot Water Cleaning of Engine Pack at Fort Lewis	5-16

WDR111/029

FIGURES .(Continued)

		<u>Page</u>
4-6	Zero Discharge Reverse Osmosis System	4-20
4-7	Ion Exchange System for Chromic Acid Recovery	4-23
4-8	Electrodialysis Recovery System	4-25
4-9	Spray Rinse System	4-38
4-10	Zero Discharge Hard Chromium Plating System	4-39
4-11	Assortment of Conforming Anodes	4-47
4-12	Reversible Rack with Conforming Anode	4-47
4-13	Chrome Plating Bath with Two Bus Bars and Reversible Rack	4-48
4-14	Spray Rinse of Plated Part and Reversible Rack	4-48
4-15	Hand Spray Rinse	4-49
4-16	"CatNapper 10" Electrolytic Plating Bath Purification System	4-49
4-17	Flow Diagram of Tobyhanna Army Depot Metal Finishing Wastewater Treatment System	4-63
5-1	Tracked Vehicle During Field Manuevers	5-4
5-2	Tracked Vehicles Can Accumulate Up to a Ton of Soil During Field Activity	5-5
5-3	Oily Engine Compartment of an M-60 Tank	5-8
5-4	Conventional Open Arch Solvent and Detergent Cleaning of M-60 Tank Engine Pack	5-8
5-5	Conventional Vehicle Wash Facility at Fort Polk	5-11
5-6	New "Bird Bath" Central Vehicle Wash Facility at Fort Polk	5-11
5-7	Water Monitor Helps to Clean Tank Exterior at Fort Polk	5-12

The major discharges of hazardous waste from typical metal plating facilities are rinsewater contaminated by drag-out from various cleaning and plating baths; cleanup of spills; disposal of acid and alkaline cleaners; and occasional plating bath dumps.

The most common process modifications that have been implemented at DOD plating shops to reduce generation of hazardous wastes are:

1. Material Substitutions
2. Rinsewater Modifications
3. Processes to Recover Metals

With respect to material substitution, traditionally cadmium has almost universally been plated from alkaline cyanide baths, due to the improved plate resulting from the stable cadmium cyanide complexes. Unfortunately, cadmium cyanide baths are costly and dangerous to operate and expensive to treat.

The NARF at North Island (4.4.1) has partially switched from plating steel parts for corrosion resistance with cadmium wet baths to coating parts with aluminum using Ion Vapor Deposition (IVD). This substitution eliminates the environmental problems associated with cadmium and cyanide. For the past 7 years, metal parts such as landing gears, bolts, and tail hooks have been plated with the dry IVD process. Advantages of the process include safer working conditions, a higher operating temperature, improved throwing power, and better adhesion of the aluminum coating compared to that achieved with cadmium. However, the process is considerably more complex and requires more labor and skill than does cadmium plating. For this reason, the process has been used for few parts, and new parts are evaluated on an individual basis to determine the preferable plating technique. The process change has not significantly reduced the amount of cadmium plating performed at the facility.

Lockheed's plating shop (4.4.2) located in Air Force Plant #6, in Marietta, Georgia, switched from an alkaline cyanide cadmium bath to a proprietary acidic non-cyanide-containing cadmium bath. Lockheed found that the product quality improved as a result; however, more careful process control is required. Although the new plating solution, costing approximately \$3 per gallon, is more expensive than the old cyanide-containing formulation, reduced waste treatment costs have resulted in a net cost savings for this modification. As a result of this modification, alkaline chlorination for the treatment of cyanide is no longer needed. The material substitution was implemented primarily to reduce the safety hazards associated with the operation and disposal of cyanide baths. An improvement in quality and a

reduction in total costs led to the permanent adoption of the process modification.

Rinsewater modifications reduce flows that must be processed in wastewater treatment plants; however, the amount of toxic metals generally remains the same. If rinse flow rates are reduced sufficiently, it is possible to utilize rinsewater to make up for evaporative losses in the plating tanks, resulting in metal recovery and reduced waste discharge.

Various DOD facilities have installed flow restriction valves, timers, and conductivity controls on the rinsewater supply line to reduce wastewater quantities. Timers or conductivity controls regulate the frequency at which rinsewater is supplied to the rinse tank. The control valve will open after a certain time cycle or when the conductivity of the rinsewater exceeds a specified value. Conductivity controls have not performed well in most military installations because of the probes' lack of ruggedness and need for frequent calibration and cleaning.

The Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California has implemented many of the above-mentioned process modifications at Pensacola NARF (4.4.3) to reduce wastes generated by the hard chromium plating shop. They have retrofitted an existing countercurrent rinse tank with a recirculating spray rinse system which reduces rinsewater requirements sufficiently that the rinsewater can be used for plating bath makeup. A pump recirculates rinsewater through eight high velocity spray nozzles located around the perimeter of the rinse tank. The pump is activated by a foot pedal as parts are lowered into the empty tank. Clean rinsewater is available via a hand-held sprayer. After repeated use, a portion of the rinsewater is pumped through a cloth filter into the plating tank and added to the plating bath to replace water lost through evaporation. Plating baths are operated at elevated temperatures to increase the rates of both evaporation and plating. These modifications have reduced freshwater use from 350,000 gallons per month for countercurrent rinsing to about 1,200 gallons per month of makeup water for spray rinsing. Since this amount was less than the evaporation rate, all of the spray rinse was returned to the plating bath, resulting in a "zero discharge" condition. A total savings of approximately \$25,000 per year per bath was projected, principally due to reduced industrial wastewater treatment costs.

Without drag-out to aid in removal of contaminants from the bath, a cleanup process was required to reduce the need for plating bath dumps. An electrolytic bath purification system was installed to continuously remove cations from the chromium plating solution. The system uses cathodes contained within membrane modules and anodes to oxidize

trivalent chromium to hexavalent chromium and to selectively precipitate cation impurities from the plating solution. Hexavalent chromium ions remain on the anode side of the membrane, and are returned to the plating bath. The purification system did not effectively remove contamination from the chromium plating bath during a trial run. The system experienced failure of the membrane modules, caused by a change of material by a supplier. Although replacement of the membrane modules is expected to rectify the problem, further testing is required before this technology can be recommended at other DOD facilities.

NCEL implemented these process modifications at Pensacola as a test prototype system. Although NCEL has proved that the spray rinse system is effective in removing drag-out, plating personnel remain skeptical about the effectiveness of the spray rinse system. Despite resistance from platers, there are plans to construct a permanent spray rinse and bath purification system, given the prospect of reduced wastewater flows and treatment costs. At other military installations where the spray system was installed, the rinsewater modifications have been received more favorably because an extensive training program was provided prior to startup. In addition, engineering and management have been very supportive of the process modifications. That these plating modifications have succeeded is due in large part to the dedication of Mr. Charles Carpenter, of NCEL, who originated the new system, diligently supervised its implementation, and remained available for ongoing consultation.

Recovery processes, such as evaporation, reverse osmosis, electrodialysis, and ion exchange, have been suggested to remove impurities from plating baths and concentrate rinsewaters so that they can be used for bath makeup.

Pensacola NARF and Charleston NSY (4.4.4) tested a LICON system for the recovery of chromium from hard chrome plating line rinsewater. The system consisted of a cation exchange unit for removal of contaminating cations and a vapor recompression evaporator to concentrate the cleaned rinsewater back to plating bath strength. The system was plagued by failure of seals and severe corrosion of the carbon steel compressor. Moreover, the initial feasibility evaluation was based on the amount of drag-out experienced from decorative chromium baths rather than the significantly lower quantity of chromium available from hard chrome plating. The system was complicated and required excessive operation and maintenance attention.

Anniston Army Depot's plating shop (4.4.5) has reduced hazardous waste production by carefully operating and maintaining plating baths so that the need for bath dumps is nearly eliminated.

Tobyhanna Army Depot (4.4.6) treats metal and cyanide wastes in an innovative treatment plant which employs cyanide destruction, chromium reduction, and metal sulfide precipitation. This process has been hindered by operational and maintenance problems and a lack of coordination between environmental and production personnel.

VEHICLE WASHRACKS

Tactical vehicles and equipment used at Army bases are typically washed and cleaned prior to servicing at a common washrack located at individual motor pools. Each base has 2 to 45 washing locations with a total of 30 to 80 washracks. Exterior washing involves removing road dirt and sediment from tracked and wheeled vehicles and any ancillary equipment. Sometimes detergents and solvents are used to assist in exterior cleaning. Washing is generally conducted whenever the vehicles are returned from field maneuvers.

Scheduled maintenance is usually preceded by removing the engine from the vehicle and cleaning both the engine and its compartment. Cleaning prior to servicing often removes large quantities of petroleum, dirt, and vegetation. Solvents are regularly used to assist in the cleaning operation. Servicing is conducted on a scheduled basis, usually quarterly.

Many facilities were having difficulties meeting NPDES permit requirements because wastes were being discharged with stormwater but without adequate treatment. Many Notices of Violation were issued by state and federal permitting authorities.

In addition to a lack of wastewater treatment, other deficiencies of the combined washing facilities include inadequate water pressure, ineffective solvent and oil collection facilities, and undependable steam cleaners. Remedies for each of these deficiencies can help reduce the generation of hazardous wastes through reduced use and better containment of solvents.

Planning for process modifications to reduce water and solvent use began in 1974 at the Construction Engineering Research Laboratory (CERL). The concept that was developed involves segregating external vehicle cleaning from maintenance servicing. The wastewater would thus contain less solvents and detergents, so that the only treatment needed would be to remove suspended solids and a small amount of oil before the wastewater could be recycled.

Ft. Polk (5.4.1), located in Louisiana, has two central vehicle wash facilities, each with 3 lanes designed for tracked vehicles. Large washing basins, referred to as "bird baths," have been installed to help remove heavy soil

which accumulates within the tracks and on the underside of the vehicles.

The bird bath is filled with water and the vehicles drive through for the primary washing action. Two staggered rows of 24-inch concrete-filled pipes are installed at the bottom of each lane, causing a teetering action when a tank or other tracked vehicle drives through. The tracks extend through their entire range of motion as they move over the corrugations on the bottom of the bird bath, dislodging caked-on soil.

One lane at each central vehicle wash facility has been modified by inserting concrete parking curbs between corrugations to enable use by wheeled vehicles. Water monitors (spray cannons) provide secondary cleaning. Washrack facilities are provided with hoses to clean the inside of vehicles after they exit the bird bath. Waste washwater is discharged to a sedimentation lagoon for suspended solids removal and reuse. Little makeup water is required.

The only maintenance problem noted was erosion of seals and other components of the four buried butterfly valves used to control discharge from the bird baths. One unanticipated problem was theft of the brass water monitor nozzles, presumably for their pawn shop value.

The central wash facilities are able to produce cleaner vehicles than the older washracks. At the old washracks, it was estimated to require 12 persons 3.5 hours to wash 6 tracked vehicles. At the central wash facilities, it was estimated to require 12 persons 1 hour to wash 25 tracked vehicles.

Ft. Lewis (5.4.2), located in Washington State, has installed a series of new washracks in each of three central vehicle wash facilities, consisting of overhead booms and hoses supplying 30 gallons per minute of water at a pressure of 90 psig. Separate lanes are provided for tracked and wheeled vehicles. Bird baths were not used because the Washington soils are lighter than Louisiana soils found at Ft. Polk. With the lower pressure water in the old system, a vehicle required approximately 2 hours for cleaning. With the new high pressure system, a tracked vehicle can be washed in approximately 20 to 30 minutes and a wheeled vehicle in 15 to 20 minutes.

Waste washwater is collected in a drain, then treated prior to recycle. Treatment processes include API oil/water separator, equalization, and intermittent sand filtration. The reclaimed washwater is pumped from the detention basin for

reuse. At one of the vehicle wash facilities, water is not recycled but is discharged to the sanitary sewer.

Two commercial vehicle wash facilities have been installed in conjunction with the central wash facilities. One serves primarily cars and has operated well. The other, serving irregularly shaped wheeled vehicles, has had numerous operating and maintenance problems.

At Ft. Lewis, facilities were designed to provide a covered location for scheduled maintenance to eliminate discharge of solvent and oil-laden water to storm drains. High pressure, hot water is supplied for cleaning and to reduce the need for solvents and detergents. Previously, steam was used for this purpose at the older washracks. Safety problems associated with the high temperatures of the steam have mostly been eliminated with the hot water system.

The waste stream from combined washing and servicing operations had been discharged to the storm sewer. The waste contained large amounts of oil and solvents, leading to numerous violations of the discharge permits. In addition to separating exterior washing from service washing, oil/water separators have been installed on the storm drain discharges. The combination of reduced solvent use, better control of waste oil, and installation of oil/water separators has led to a 90 to 95 percent reduction in the contaminants being discharged through the storm sewers to surface water. Discharges are now regularly meeting NPDES limitations.

The cases are listed in Table 1, along with their composite scores. These scores were based on each case's usefulness as an example and its degree of success with the process modifications. A detailed explanation of the scoring process is presented in Chapter 6.

WDR111/014

Table 1
SUMMARY OF CASE STUDY EVALUATIONS

Report Section	Facility, Modification	Service	Composite Score
3.4.1	Hill AFB, Dry Paint Stripping	Air Force	19.5
4.4.3	Pensacola NARF, Spray Rinse	Navy	19.5
5.4.2	Fort Lewis Army Post, Vehicle Washracks	Army	18.5
3.4.6	Robins AFB, Solvent Recycle	Air Force	18.0
3.4.2	Pensacola NARF, Dry Paint Stripping	Navy	17.9
5.4.1	Fort Polk Army Post, Vehicle Washracks	Army	17.4
3.4.7	Norfolk NSY, Solvent Recycle	Navy	16.5
4.4.5	Anniston Army Depot, Plating	Army	15.8
3.4.3	Pensacola NARF, Water Primer	Navy	15.4
3.4.5	Hughes (USAF), Powder Coating	Air Force	15.0
4.4.2	Lockheed (USAF) Cd Plating	Air Force	14.9
3.4.10	Anniston Army Depot, Solvent Recycle	Army	14.4
3.4.4	Lockheed (USAF), Painting	Air Force	14.0
3.4.8	Tyndall AFB, Solvent Recycle	Air Force	13.4
4.4.6	Tobyhanna Army Depot, Waste Treatment	Army	11.9
3.4.9	Norfolk NARF, Heptane Recycle	Navy	11.3
4.4.1	North Island NARF, IVD of Aluminum	Navy	10.7
4.4.4	Charleston NSY, LICON Chrome Recovery	Navy	10.3

Introduction

1. INTRODUCTION

At the 1984 annual meeting of the Water Pollution Control Federation, Abel Wolman, Professor Emeritus of Johns Hopkins University, proposed a three-pronged attack on the hazardous waste problem:

1. Industry should reduce the production and use of hazardous materials to a minimum.
2. The reduced waste volume produced by industry should be treated to the greatest extent possible so that a minimum quantity of hazardous waste is discharged to the environment.
3. The water supply industry should provide final protection of public health and welfare in removing whatever hazardous substances remain.

In making this appeal, Dr. Wolman stressed that these three steps be undertaken in sequence and that every effort be made in one step before moving on to the next. Just as it has often proved more effective to protect a watershed through wastewater treatment than through extensive water treatment, reducing the quantities of industrial waste produced can have a beneficial effect on hazardous waste disposal and wastewater treatment.

Frequently, when we refer to reducing industrial waste discharges, we think of end-of-pipe treatment facilities. Dr Wolman emphasized that treatment should come as a last resort, after every effort has been made to eliminate the hazardous waste produced from the processes themselves.

1.1 Background

Since 1980, with the issuance of policy memorandums DEQPPM 80-5 and DEQPPM 80-8, it has been DOD policy to limit the generation of hazardous waste through alternative procurement policies and operational procedures that are both environmentally attractive and fiscally competitive. The Army, Navy, and Air Force were directed by DOD to reduce quantities of hazardous waste, when feasible, through resource recovery and reclamation, recycling, source separation, and raw material conservation.

In carrying out the intent of these policies, many studies have been performed which recommended industrial process modifications that, if successfully implemented, have the potential to significantly reduce the generation of hazardous wastes at the source, rather than treating them at end-of-pipe facilities. Several modifications have been successfully implemented, and many others either were not implemented or failed to meet their goals.

CH2M HILL was contracted by the DOD Environmental Leadership Project and the U.S. Army Corps of Engineers to evaluate 40 cases of industrial process modification attempted by the three armed services to reduce their generation of hazardous wastes.

1.2 Project Objectives

The ultimate goal of the project was to encourage the development and implementation of industrial process modifications that would reduce the amount of hazardous waste generated by the armed services.

Major objectives of this project were to determine why some of these process modifications have been successful and others have not, and to recommend actions to make future modifications more successful. CH2M HILL was to evaluate not just technical factors, but also institutional and motivational factors that contributed to success or lack of success. This report is the product of Phase 2 of a three-phase effort for the Defense Environmental Leadership Project, which is aimed at accomplishing the intent of the above-noted DOD policies. The three phases of the project are described as follows:

- Phase 1: Evaluate 40 cases of industrial process modifications, taken from the Army, Navy, and Air Force, and recommend 18 of those cases for further study during Phase 2. The primary factor in evaluating the cases was not whether they had been successful, but rather whether they were useful as examples of how such processes could be implemented. Identify any R&D requirements for which there is a need.
- Phase 2: Evaluate in depth the 18 cases selected from Phase 1, and recommend three as "Projects of Excellence" to be promoted during the final phase of the project. The report is to identify the management, training, and incentive programs developed and put into place along with the technology that stimulated acceptance and successful implementation of the selected process modifications.
- Phase 3: Promote the three "Projects of Excellence," using employee training and briefing programs to encourage the development and implementation of similar projects, and emphasize commitment to DELP's ultimate goal, which is to reduce the generation of hazardous wastes.

1.3 Sources of the Cases Studied

Of the 40 cases examined in Phase 1, 32 represent the three industrial processes which generate the greatest portion of DOD hazardous wastes (painting and paint stripping, electroplating, and solvent cleaning). All of the 18 cases evaluated in Phase 2 of the project were related to these processes. Also, most of the cases of process modifications covered in this report occur either in manufacturing or in repair and reconditioning facilities.

Manufacturing usually is performed by civilian contractors operating government-owned, contractor-operated (GOCO) facilities, such as Air Force Plant 6, where Lockheed manufactures and modifies cargo planes. To extend service life, military equipment is repaired at the point of use and periodically reconditioned at centralized facilities. The repair and reconditioning facilities are typically government-owned and government-operated (GOGO); the Anniston Army Depot, which is responsible for the reconditioning of armored vehicles, is one such facility.

Metal finishing operations, which are performed at over 100 DOD industrial facilities, produce most of DOD's hazardous waste. Metal finishing can be performed on new parts as part of the manufacturing process, or as a means of repairing or remanufacturing equipment.

DOD metal finishing shops perform a variety of operations, including: paint stripping and painting; cleaning for removal of dirt, oils, greases, and corrosion products; and electroplating. Each of these operations results in the production of hazardous wastes that must be properly handled and disposed of.

Paint stripping is a major hazardous waste generator at DOD facilities. The case studies evaluated involved paint stripping of aircraft and parts. Typically, acidic methylene chloride or phenolic paint strippers are sprayed on the plane to dissolve the paint, which is then physically removed. The paint-solvent mixture generally falls to the floor beneath the plane and is washed into the facility's wastewater collection system. Paint that cannot be chemically stripped is usually physically removed by sanding, a tedious and expensive process that also causes considerable damage to the corrosion protection coatings on the aircraft. Modifications investigated include new mechanical and physical techniques for stripping the paint, such as dry media blasting using a soft recoverable plastic media, laser stripping, and solvent reuse.

Painting is common to virtually all DOD industrial facilities. Painting modifications studied involved reducing the use of volatile solvents, by selecting

substitutes such as water-based primers, and using powder coating, high-solids coatings, wet electrostatic painting, etc. Before either maintenance or painting, metal surfaces are often cleaned with solvents and cleaners to remove accumulated dirts, oils, greases, and corrosion products. Solvents are also used to thin paints and in paint cleanup.

Most process modifications implemented to recover and reuse a portion of the solvents used involve the addition of distillation systems. Several types of distillation systems were examined, including atmospheric stills, vacuum stills, indirectly heated stills, and stills using direct steam injection. Other solvents and organic fluids were recycled by unique innovative treatment and recovery processes.

Modifications that were investigated to reduce waste generation from electroplating facilities include: metal recovery from rinsewaters, reduction of rinsewater volumes, plating bath cleanup techniques to reduce frequency of disposal, conversion from cyanide to noncyanide plating baths, and ion vapor deposition of aluminum in lieu of cadmium plating for corrosion protection.

Vehicle washing and maintenance cleaning can be significant sources of contaminants at Army facilities. Until recently, these functions were performed on open pads. The use of solvents and detergents for engine cleaning and spills during transfer of petroleum, oil, and lubricants (POL) has resulted in stormwater runoff contamination. Modifications to vehicle washing evaluated include the segregation of exterior cleaning from maintenance through the use of central vehicle washracks and improved covered maintenance stands.

In addition, cases investigated in Phase 1 but not investigated further in Phase 2 involved explosives manufacturing, jet engine test cells, fire fighting training, fuel tank cleaning, and purchase and use specifications. These cases involved process modifications to reduce discharges of pink water and oxides of nitrogen from explosives manufacturing, conversion to dry jet engine test cells, a change in chemicals used for fire fighting training, changing the frequency of fuel tank cleaning, and modifying purchase and use specifications to reduce the disposal of materials due to expired shelf life.

A description of the scope of work is presented in the next chapter of this report, followed by descriptions of the process modifications, and conclusions and recommendations, including an evaluation of the 18 cases studied in Phase 2 and recommendations of the three cases for Project of Excellence designation.

WDR111/015

Scope of Work

2. SCOPE OF WORK

Under the General Statement of Services in the contract under which this project was performed, the Architect-Engineer (CH2M HILL) is charged to:

- Review and analyze existing studies on industrial process modifications to reduce the generation of hazardous wastes.
- Identify techniques and the climate that are necessary for the modifications to be successful.
- Develop programs to assure successful adoption of environmental control and hazardous waste reduction programs.

The Scope of Work applicable to Phase 1 of the project is detailed as follows:

- 2.1 The AE shall apply innovative approaches to this project as the basis for positive, action oriented results. The AE shall identify any R&D requirements for which there is a need. The study reports will include justification to support all recommendations.
- 2.2 The AE shall investigate and analyze industrial process modifications to reduce hazardous waste generation.
- 2.2.1 The AE shall review and analyze 40 studies, by either the services themselves or previous contractors who have investigated the various industrial process modifications to reduce hazardous waste generation. The studies will include: (1) Industrial processes which were studied and found to be acceptable for modifications and then were successfully modified with the changes implemented and operated according to the plan proposed in the original study. (2) Industrial processes which were detailed and found to be acceptable for modification but which were not successfully modified with the changes implemented and operated according to the plan proposed in the original study.
- 2.2.1.1 The AE shall prepare a report of the analysis performed on the 40 studies considering items such as costs, energy consumption, practicality, management, incentives, and program monitoring and auditing. This report shall stand alone and

VOC Air Emissions

The current EPA air emission standards are a result of the Clean Air Act of 1977 that mandated all states to meet "National Ambient Air Quality Standards" (NAAQS). Implementation of the lower EPA-recommended paint VOC limitations is only a small part of each state's program. The main thrust of the NAAQS regulations is to control "photochemical reactive" volatile organic compounds commonly identified as smog-producing organics. Exempted from the regulations are certain VOCs, such as methylene chloride and 1,1,1-trichloroethane, of negligible photochemical reactivity (4). The new "compliance paints" were developed to meet the EPA-recommended standards.

To comply with these new regulations, paint formulations have been changed by substituting exempt solvents for controlled solvents, decreasing solvent content (as in high-solids coatings), and developing new low solvent formulas (as in water-based coatings).

Of primary importance in understanding these regulations is that they are intended to control smog-producing organics and are not designed to control the toxic hazards. The previously discussed NESHAP program that will regulate toxic air pollutants may completely change current paint, paint stripper, and cleaning solvent formulations. EPA limits regulated VOC compounds in paints to 420 g/L. California has set stricter limits which other states may follow as NESHAP "State Implementation Plans" (SIP) are implemented to meet EPA's NESHAP compliance deadline of December 31, 1987 (4).

In summary, compliance with requirements for using hazardous materials is becoming very costly. The problem goes beyond what the military and industry have historically practiced and will include comprehensive requirements for all aspects of hazardous materials handling and disposal. Painting and solvent cleaning processes use many of the hazardous materials that are now or will be covered by the regulations. Complying with the regulations will require expenditures for training, record keeping, etc., in addition to the significant costs of retrofitting existing facilities that may be necessary. In some cases the costs may be prohibitive at a specific location, and operations may have to be moved to a more environmentally acceptable location. Some chemicals may be regulated such that present practices are prohibited, requiring that alternatives be found. Implementing programs which reduce hazardous wastes will not only reduce the problems involved with hazardous waste handling and disposal, but will also provide better and less costly compliance with general environmental, health, and safety regulations.

developed to control toxic air emissions. EPA has only started the program, so major policies, program direction, and regulation standards have not been developed. However, the compounds most likely to be evaluated first to determine if air emission limits are needed are the "priority pollutant compounds" (toxic pollutants given consideration for developing wastewater and hazardous waste regulations). The priority pollutant compounds common to painting and stripping operations include trichloroethane, phenols, toluene, methylene chloride, and trichloroethylene. The NESHAP regulations will probably override any existing VOC regulations. For example, existing VOC regulations for paints limit the total volatile organic contents of paints whether the volatile compounds are toxic or not. The NESHAP regulations may specifically limit a compound, such as toluene, in the paint formula or regulate its use in solvent cleanup and stripping solutions unless adequate air pollution control equipment is installed. An example of expected EPA actions is provided in a report which discusses possible inclusion of methylene chloride on EPA's "Fast-Track" list of potential toxic air pollutants. Pollutants on this list would be reviewed on a fast track basis to determine if regulatory standards are needed (9).

Health and Safety Regulations

OSHA regulations and standards cover worker safety and must always be considered when chemicals are involved. OSHA regulations prescribe proper health and safety requirements for using and holding the paint, solvent, and stripper chemicals. Regulating safe worker exposure limits to toxic organic compounds used in painting and solvent processes is the responsibility of OSHA. OSHA has set maximum exposure limits for most solvent process chemicals. These standards are normally met by providing adequate work area ventilation and fresh air. One of the new OSHA programs now being implemented is the "Hazardous Communication Standard," commonly referred to as "right-to-know" standards (10). These regulations require additional time and expense by DOD facilities to comply with the regulations where hazardous chemicals are used. The OSHA Hazard Communication Standard mandates, for the first time on a national level, that chemical manufacturers evaluate the possible hazards of their chemicals and adequately communicate the information to the users. Employers are required to keep employees duly informed of the OSHA rules, informed of any operations in their work area where hazardous chemicals are present, and trained in the health and safety aspects for working with each chemical. All employers are required to have the hazard communication program in effect by May 25, 1986.

Wastewater Pretreatment Regulations

The EPA has established "National Categorical Pretreatment Standards" that limit wastewater contaminant concentrations which can be discharged to publicly owned treatment works. Painting, paint stripping, and solvent cleaning and degreasing wastewaters are specifically included in the EPA standards for metal finishing facilities if the facility processes also include any one of the major metal finishing operations: electroplating, electroless plating, anodizing, coating, chemical etching and milling, and printed circuit board manufacturing (40 CFR 433) (8). Since almost all DOD facilities which include painting and solvent cleaning processes also perform one or more of the six specific metal finishing operations, the metal finishing pretreatment standards will apply. The specific discharge limitation impacting painting and solvent operations is the "Total Toxic Organic" (TTO) limit. The term "TTO" means the total of all toxic organics listed (40 CFR 413.11), which includes most common paint solvents, stripper compounds, and cleaning solvents, such as trichloroethane, tetrachloroethylene, dichlorobenzenes, creosols, toluenes, phenols, and trichloroethylene. The final TTO limitation for discharges to publicly owned treatment works becomes effective July 15, 1986 for electroplating processes and February 15, 1986 for the other metal finishing categories (interim TTO limitations may apply to certain cases). The TTO limit will be 2.13 mg/L daily maximum, and EPA recommends a long-term effluent concentration TTO average of 0.434 mg/L as a basis for design and operation in order to comply with the maximum limit (8). Direct discharge limitations are more strict, with a maximum daily TTO of .058 mg/L. State and local regulatory agencies implement these regulations. Many local municipal treatment plants set more stringent standards, as do states, for direct discharges. For example, Texas has set a 0.3 mg/L TTO limit for NAS Corpus Christi direct discharge, and Norfolk Municipal Wastewater Plant has set a 2.0 mg/L phenol limit for NAS Norfolk. Disposal of painting and solvent wastewaters will become more costly and will require more sophisticated treatment systems to remove the hazardous contaminants as regulations limiting toxic discharge are tightened. On-base wastewater treatment systems installed to meet these requirements will produce additional hazardous sludges which will require hazardous waste disposal.

Toxic Air Emission Regulations

Regulations specific to atmospheric emissions of hazardous materials are being developed by EPA in the "National Emission Standards for Hazardous Air Pollutants" (NESHAP) program. Presently there are no national toxic air emission standards for the types of solvents used in painting and solvent cleaning that are based on environmental hazard considerations. In EPA's NESHAP program, regulations are being

3.2 Magnitude of the Problem

3.2.1. Solvent-Related Hazardous Wastes--Environmental Compliance

Painting, paint stripping, and solvent cleaning and degreasing are common to virtually all DOD facilities. Consequently, the pollution and waste disposal problems created by these processes are significant. Environmental regulation plays a key role in how wastes are managed and, in some cases, dictates what paints, solvents, and miscellaneous chemicals can be used. Solvent-related process wastes can be categorized into three principal groups: hazardous wastes (liquids, sludges, and solids), wastewater (discharges to municipal treatment waters or waterways), and air emissions. Environmental regulations covering the generation, handling, treatment, and disposal of the waste materials are established by federal, state, and local regulating agencies. In many cases the regulations and agency authorities overlap, vary considerably, or in fact conflict with each other. As an example, California has 13 state agencies which in some way regulate hazardous waste. In addition to the state, county, and local regulations that may apply, most regulations follow federal EPA standards and guidelines. For the general discussion of environmental regulations which follows, EPA regulations are used as the basis for defining the magnitude of both the environmental and regulatory aspects of the problem.

Hazardous Waste Regulations

Almost all paint, paint stripping, and solvent cleaning and degreasing wastes are considered hazardous wastes by EPA criteria. For paints containing heavy metals, the EPA toxicity test (40 CFR 261.24) may apply; it sets maximum concentrations for heavy metals, including cadmium (1 mg/L), chromium (5 mg/L), and lead (5 mg/L). Solvent and paint wastes are classified as hazardous if they are ignitable (40 CFR 261.21). Solvent and paint wastes are listed hazardous wastes by generic definition (40 CFR 261.31); this includes general spent solvents and specifically trichloroethylene, xylene, toluene, methylene chloride, and methyl ethyl ketone (all common solvents). Specifically listed hazardous wastes such as discarded commercial chemical products, off-specification species, containers, and spill residues include many of the common solvents (40 CFR 261.33). Some state regulations classify all paint and solvent waste as hazardous unless proven otherwise (7). Therefore most (if not all) solvent process and painting facilities produce hazardous wastes that must be managed in accordance with federal, state, and local regulations.

Vapor Degreasing

This process uses nonflammable, chlorinated hydrocarbons in a vapor phase to clean metallic and other suitable surfaces. A special apparatus is used to provide solvent vapor for cleaning. This apparatus consists of a tank, in which the lower 10 percent of the volume is full of solvent. This solvent is heated, usually by steam coils, to its boiling point, producing solvent-saturated vapor in the upper portion of the tank. The item to be cleaned is either inserted manually or automatically into the vapor region, where hot solvent vapor immediately condenses onto the surface of the item. The condensed solvent then drips back into the liquid bath with the removed dirt and grease. The solvent vapor is usually prevented from escaping to the atmosphere by use of a refrigerated section on the upper part of the tank. The solvent condenses on the walls of this section and returns to the liquid sump.

The most common solvents used in vapor degreasing are trichloroethylene, perchloroethylene, 1,1,1-trichloroethane, and methylene chloride (6). Trichloroethylene is by far the most popular vapor degreasing solvent. Its relatively low boiling point (87° C) allows for the use of low pressure steam for heating and permits handling of parts immediately after cleaning. The second most popular solvent is 1,1,1-trichloroethane. This solvent is popular because of an even lower boiling point than that of trichloroethylene; however, since it is reactive with zinc and aluminum, it cannot be used to clean those materials. Perchloroethylene is used in about 15 percent of vapor degreasing applications. It is very stable, has a very high boiling point, and is the least aggressive solvent. Other solvents used in vapor degreasing include fluorocarbons (Freon) and carbon tetrachloride.

Metal Preparation and Precision Cleaning

A common method of surface preparation for the application of coatings to metallic surfaces is to clean the surface with a solvent such as alcohols, ketones, esters, or cresylic acid. The solvent is usually consumed in the process.

The cleaning of precision instruments and electronic components requires solvents of high purity, high solvency, and rapid evaporation rates. Freon compounds are customarily used for these applications.

Fuel Flow Meter Calibration

Since jet aircraft fuel (JP-4 and JP-5) is a blend of organic compounds and varies widely in density and other properties, uniform fuel flow meter calibration is a problem. The DOD uses several calibration fluids, one of which is heptane.

control agencies are setting more strict VOC content limits for paint. For example, the South Coast Air Quality Management District in California has set a 350 g/L VOC limit for aircraft paints (4). Local regulatory agencies also control VOCs by setting total permissible discharge limits from facilities which include point sources and fugitive sources. The EPA is required to develop limitations in toxic emissions in the future; these will likely impact both the types of solvents used in paint and solvents used in cleanup.

3.1.3 Solvent Cleaning and Degreasing

Solvent cleaning and degreasing is the process of removing unwanted grease, oils, and other organic films from surfaces using an organic solvent in which the unwanted film is soluble. The pollutants generated include the liquid waste solvent and degreasing compounds containing the unwanted film material and air emissions containing the volatile solvents. In almost all cases, solvent cleaning and degreasing is utilized to some extent in preparing surfaces for painting. Another solvent-based process, fuel flow meter calibration, generates similar wastes. The process is included in this section because the magnitude of the problem is similar and the same alternative solvent waste reduction methods are applicable. In addition, several of these processes are normally found at each installation, reinforcing the need for an integrated approach to overall waste reduction.

There are three distinct types of operations involved under the category of solvent cleaning and degreasing: cold cleaning, vapor degreasing, and metal preparation and precision cleaning. The most common other solvent use is for fuel flow meter calibration. These process waste sources are described below.

Cold Cleaning

This is the simplest, least costly, and most common type of solvent cleaning. The solvent is usually applied at ambient temperature or slightly heated. It is applied either by brush or by dipping the items to be cleaned in a solvent dip tank. The most common solvent used for this application is known as PD-680 (Mil-Spec) or by the proprietary commercial name of Stoddard Solvent or Varsol. This solvent is a mineral spirit that is highly flammable. It is generally the cheapest solvent used for cleaning and costs between \$1.00 and \$2.50 per gallon (5).

mixed with a carrier, usually organic solvent, and applied to the surface with an air or airless pressurized sprayer. Spray painting is usually done in a horizontal or downdraft paint spray booth for smaller items, or a paint hangar for whole aircraft or other large equipment items.

The two most significant sources of hazardous waste generated in painting processes are paint sludges and waste solvents. The largest volume of hazardous waste generated in painting involves air emissions. During spraying, 50 percent of the paint is deposited on the surface being painted and the other 50 percent, called overspray, is sprayed into the air (3). As the paint "dries" the solvent evaporates to the air. The air from the paint booth or hangar is often exhausted through a water scrubber which scrubs the paint from the air. The scrubber water is normally recycled, and paint solids are concentrated in the scrubber sump. When the sump fills with paint sludge, the sludge is removed and drummed for hazardous waste disposal.

The second significant source of hazardous waste generated in painting processes is the use of solvents to clean painting equipment. Most paints used by the military are solvent-based, meaning that they require solvents for cleanup. The type of solvent used varies with the paint. Some of the more common solvents are methyl ethyl ketone (MEK), xylene, 1,1,1-trichloroethane, toluene, butyl acetate, ethylene glycol, monoethyl acetate, and alcohol. In addition, paint stripping solvents (as described in Section 3.1.1) may be used to clean hardened paint surfaces. These wastes are classified as hazardous because of their general flammable and toxic properties.

Many painting processes generate unique types of hazardous waste. The common feature of almost all of these wastes is that their hazardous characteristics are derived from the paint constituents (heavy metals and solvents) and the solvents used in cleanup (toxic and flammable organics). For example, when dry scrubber paint booths are used instead of water scrubbers, the filter material can become contaminated with the paint and require disposal as a hazardous waste. Water-based paints are used, reducing the use of solvents for cleanup and therefore reducing the volume of hazardous waste generated. At some installations the water scrubber water is discharged to the onsite industrial treatment plant, where the paint residue is removed along with the other treatment plant sludges.

Another environmental discharge from painting is VOCs emitted to the air. Presently, EPA only regulates VOC emissions from paint coatings and has no regulations regarding solvents used in cleanup. VOC limits for paint are 420 g/L for paints which cure below 90°C and 360 g/L for paints curing above 90°C (3). Some state air pollution

Table 3-1 (continued)
PAINT STRIPPER AND CORRESPONDING PAINT SYSTEMS

Paint Remover/Mil-Spec	Paint Stripper	Components	Corresponding Paint Systems
			Paint System/Mil-Spec
Turco 3823 or B&B 7219T or Omega SN (322-12) (or equivalent)	Ortho dichlorobenzene, amine, cresols		Phenolic resin (for aluminum with aluminum inserts or plasma spray)
Mil-D-26549	KOH		Phenolic resin (for steel and magnesium)
Eldorado SR-46 or EZE 500-81	---		Polysulfide sealant/Mil-S-8802
EZE 508 or Gat Ener. 5-24 or magnaflux composite stripper	---		Radome coating
Turco 4951 X	Chlorinated solvents, ammonia		Paint coatings from fiberglass
Caustic paint remover	NaOH		---
Turco T-5351	---		Epoxy paint
T-6045	---		Silicone
Mil-T-6096A or TT-T-266	---		Organic coatings from fiberglass

Air emissions generated in solvent stripping are more difficult to quantify. Emissions are expected to include concentrations of the volatile organic compounds (VOCs) in the solvent, mainly methylene chloride and phenols. Little information on the subject is available, however, primarily because these emissions have only recently come under regulation by the EPA and most state or local agencies. Thus, there has been only a minimum need to quantify these emissions to comply with OSHA requirements, which specifically concern safety. EPA is required to develop limitations for toxic air emissions, and these will affect solvent stripping operations.

3.1.2 Painting

Paint coatings are applied to surfaces of military parts, vehicles, ships, aircraft, and structures for corrosion protection, surface protection, identification, camouflage, and aesthetic appeal. Most painting is performed by conventional liquid spray technology (2). In spray painting, paint is

Table 3-1
PAINT STRIPPERS AND CORRESPONDING PAINT SYSTEMS

Paint Stripper	Corresponding Paint Systems	
Paint Remover/Mil-Spec	Components	Paint System/Mil-Spec
Epoxy system paint remover/ Mil-R-81294	Chlorinated solvent, Phenols	Mil-C-23377 and (Mil-C-81663 or Mil-C-81773A or Mil-C-22750) Mil-C-83286 Mil-C-81352
Acid activated remover for amine cured epoxy coating systems/ Mil-R-81903A	Type I - Hydroxy-acetic acid Type II - Formic acid	For coatings not removed by remover Mil-R-81294
CeeBee A238, super stripper (or equivalent)	Similar to 81294, but high percent of active ingredient	For coatings not removed by remover Mil-R-81294
Turco 5122 thin, B&B 5075 thin (or equivalent, for aluminum only)	Similar to 81903A	For coatings not removed by remover Mil-R-81294
Paint and lacquer remover/ TT-R-248	Organic solvents	Mil-P-8585 and (TT-L-32 or TT-L-20) Mil-C-8514 and Mil-P-7962 and (Mil-L-19537 or Mil-L-19538) Mil-P-23377 and Mil-L-81352 Mil-C-8514, Mil-P-8585 and TT-E-485
McGean A238M	---	Epoxy primer and Highson coat and Mil-C-83286
Organic coating remover - hot tank type/Mil-R-81903A	Trichlorethylene, ortho dichlorobenzene, cresols and all oil soaps	Organic coatings (polyurethane, epoxy, phenolic resin, alumi- nized silicone)
Carbon remover/Mil-C-19853	Chlorinated solvents, phenols, chromates	Carbon, baked primer, enamel top coats
Clarkson NA-4 (or equivalent)	---	Residual paint coatings and corrosion

are exposed to air, some of the solvent is vaporized into the surrounding area. To prevent hazardous working conditions, solvent stripping areas are ventilated with large volumes of fresh air to remove harmful solvent vapor levels. The ventilated air is normally discharged to the outside, where dilution and dispersion of the solvent vapors occur.

The hazardous and toxic characteristics of the wastes generated at stripping facilities vary considerably. The paint being stripped can contain various hazardous constituents (e.g., chromium, cadmium, lead) that will affect the degree of hazard and the disposal method to be employed. Another significant variable is that paint stripper solvents are formulated from many different compounds; this too, can significantly affect waste hazards and disposal methods. Table 3-1 lists some of the typical paint system/Mil-Spec and the corresponding solvent stripper and solvent compositions (1).

The concentrated wastewater from stripping baths and surface scraping contains mostly pure solvent and paint residue components, with associated hazardous characteristics. However, the wastes from washing contain highly variable concentrations of contaminants based on the type of paint and solvent, the amount of solvent used, and the volume of wash water used. Table 3-2 presents typical reported concentration ranges of paint stripping wastewater (1).

Table 3-2
PAINT STRIPPING WASTEWATER CHARACTERISTICS

Parameter	Range
pH, unit	6.2 - 8.0*
Phenols, mg/L	17.7 - 45.2
Methylene chloride, mg/L	3.8 - 219.2
Chromium (hexavalent), mg/L	0.10 - 1.12
Total chromium, mg/L	0.164 - 1.187
Cadmium, mg/L	0.024 - 1.09
Lead, mg/L	<.001 - 0.02

*(caustic strippers may exceed pH 10.)

3. SOLVENT-RELATED MODIFICATIONS

3.1 Descriptions of Solvent Waste Sources

3.1.1 Paint Stripping

Paint stripping is the process of removing paint and paint type coatings from surfaces, usually in preparing the surface for repainting. Solvents and/or solvent-chemical mixtures are applied to the surface so as to physically destroy either the paint coating itself or the paint's ability to stick to the surface. When this process is considered complete, the paint/solvent residue is removed from the surface, usually by a pressurized water wash and/or scraping. In many instances, reapplication of the solvent stripper is necessary to remove multiple paint coats and especially resistant paints. Wastes generated in the stripping process include the solvent/paint residue, which is collected separately at some installations, and the wash wastewater, which contains paint and solvent solid and dissolved chemicals. Collected solvent/paint residues are normally drummed and transported to a licensed hazardous waste disposal site for proper disposal.

Wash wastewater is chemically treated at onsite waste treatment facilities to remove pollutants and then discharged to municipal wastewater treatment plants for additional treatment before finally being discharged to waterways. Several facilities discharge chemically treated water directly into waterways. The onsite treatment plants generate sludge, which is generally a hazardous waste and which is transported by drum or bulk loads to hazardous waste disposal sites. Several facilities do not have onsite chemical pretreatment systems and discharge untreated wash wastewater directly to municipal wastewater treatment plants for treatment (1).^a

Another paint stripping technique, strip baths, is used to strip paint from components. In this method, components are immersed in tanks containing stripping solvent. After the solvent is allowed to dissolve the paint, the stripped parts are removed from the tank and washed with water. The stripping baths are replaced periodically, normally once or twice a year, and the hazardous waste solvent/paint liquid and sludge are disposed of at a hazardous waste disposal site. The wash wastewater is handled as previously described.

The other significant pollutant source is the solvent emissions discharged into the air. During the time the solvents

^a Corresponds to reference number at end of chapter.

Solvent-Related Modifications

2.3.2 Analyze and evaluate the training programs at the Projects of Excellence one month after exercising the option, analyze and evaluate the training aids, manuals, etc., before starting the hands-on operation sections.

2.3.3 The AE shall prepare a report on task 2.3. Prepare recommendations for implementing the positive results of this project into ongoing R&D projects to assure successful application of the management training/incentive programs at the industrial level. Provide draft DOD memos and/or directives and/or draft instructions for each of the services.

WDR111/016

identify the process modifications which should have priority for further consideration.

A Phase 1 report was previously prepared to fulfill the requirements of section 2.2.1.1 of the contract. The Scope of Work goes on to describe Phase 2 of the project.

2.2.2 The AE shall investigate and analyze 18 process modifications to be selected from the 40 studies by the Contracting Officer at the Task 2.2.1 draft final review conference. The investigation will include review of open literature and service technical reports, telephone interviews, and a maximum of 6 site-combined visits to the process sites.

2.2.2.1 The AE shall prepare a report on the 18 selected process modifications. For processes successfully modified, the AE shall report all the components and climate which contributed to, and resulted in, the success of the application of these methods. For processes not attempted or unsuccessfully modified, the AE shall report where the application process bogged down and what could have been changed to achieve success. The AE shall consider administrative, educational, and motivational methods which could have been tried or which were incorrectly applied. At the receipt of the final report, the Project Manager will identify the three Projects of Excellence.

This Phase 2 report was prepared to fulfill the requirements of section 2.2.2.1 of the contract. The Scope of Work goes on to describe Phase 3 of the project.

2.3 For 3 Projects of Excellence, the AE shall develop employee briefing and training programs to assure successful environmental control and hazardous waste reduction programs. One Project of Excellence will be developed for each service.

2.3.1 For each of the 3 Projects of Excellence, arrange an onsite visitation and instruction program, of 2 days duration, for 6 persons to be chosen by the Contracting Officer. These 6 persons will be given the employee briefing and training programs developed under paragraph 2.3. Included in the 2 days will be periods of hands-on operation of the appropriate systems used in the three Projects of Excellence. The hands-on operation will be partially monitored by the regular employee working on the system along with the AE.

3.2.2 Problem Definition--Paint Stripping and Painting

Paint stripping operations in the Navy produce an estimated 300 million gallons per year of wastewater and 9 million gallons of hazardous waste (1). Similar volumes of wastes are generated in Army and Air force facilities. The combined paint stripping waste from Army, Navy, and Air Force facilities is estimated to be over 1 billion gallons of wastewater and 30 million gallons of hazardous waste annually. Direct wastewater disposal costs are estimated to be \$2 million annually (based on average municipal disposal fees of \$2 per 1,000 gallons), and direct hazardous waste disposal costs are estimated to be \$30 million annually (based on average hazardous waste disposal cost of \$1/gallon). When all costs associated with handling and treating the wastes are included, the actual incurred total costs are probably many times the direct disposal costs. As a result of the new (and proposed future) regulations, direct waste disposal costs will no doubt increase, and could easily double or triple in the near future.

Most facilities contain both paint stripping and painting operations in the same area. Compared to the disposal of stripping process wastes, paint waste disposal is less problematic because much less hazardous waste is generated and only a small amount of wastewater is produced. An example of painting-specific waste volume is from the Lockheed-Georgia Company facility in Marietta, Georgia. At this facility, newly manufactured C-130 and C-5 aircraft and parts are painted; painting is also performed in modifying C-141 and C-5 aircraft. Hazardous wastes generated from the painting processes consist of about 50 drums per year of paint sludge and 170 drums per year of spent solvents. Hazardous waste disposal of the paint sludge costs \$3,000 per year while the spent solvents are sold to a reclaimer for \$0.15 per gallon. Of perhaps greater significance is the VOC air emissions, which were estimated at 125 tons in 1983 (about 30,000 gallons). The VOC emissions, consisting of paint solvents and cleanup solvents, include potentially toxic solvents such as trichloroethylene, toluene, MEK, and xylene, which may be subject to future toxic air emission control regulations.

For comparison, it has been estimated that current wet paint stripping operations at Hill AFB, Ogden, Utah, produce 210,000 gallons per day of wastewater to the industrial wastewater treatment plant in which it is treated at an annual cost of \$800,000. It was estimated that the paint stripping operations produce approximately 1,000 tons of hazardous waste sludge per year that is disposed of at an annual cost of \$200,000.

Wastewater pretreatment system programs require an integrated approach that takes into account all waste sources and how to best develop treatment systems to meet specific effluent criteria. Hill AFB recently completed an engineering study and cost estimate evaluating alternatives to meet the new pretreatment standards for total toxic organics (11,12). The principal waste sources contributing TTO were identified as the paint and paint stripping operations. The pretreatment system design included filtration, air stripping, and carbon adsorption treatment steps to remove TTO from the painting and stripping wastewater. The estimated system construction cost is \$2,777,750, and annual operating costs are estimated to be \$1,028,000. These costs are in addition to those of the existing onsite treatment plant, which removes metals and other conventional pollutants.

3.2.3 Problem Definition--Solvent Cleaning and Degreasing

Solvents and other organic fluids have been used at every facility that was contacted and are used in substantial quantities throughout the three services' industrial operations. The cumulative annual volume of solvents and other organic fluids used by the facilities analyzed in this section of the report is estimated to be in excess of 1 million gallons.

A recent study (13) showed that the DOD purchases and disposes of about 50,000 drums of cleaning solvents per year. The average disposal cost of \$100 per drum is one-third the average purchase cost of the solvents. The estimated total annual disposal cost for spent cleaning solvents is \$22 million. Solvents are used at almost every military installation, with major solvent usage (greater than 150 drums per year) occurring at over 150 military installations in the United States.

Based on our existing information, it would appear that the generation of waste solvents and other organic fluids is one of the most significant hazardous waste problems in the three services today.

3.3 Technologies Available to Reduce Solvent-Related Hazardous Waste

3.3.1 Paint Stripping Modifications

Paint stripping is the process of removing paint and coatings from surfaces in preparation for recoating. Complete stripping is often necessary for new paint and coatings to properly adhere to existing surfaces. In typical military paint stripping, sprays or baths containing acidic methylene chloride solutions, phenolic solutions, or hot alkaline sodium hydroxide solutions are employed to dissolve and loosen old

paint. After scraping, the resulting solvent-paint mixture is washed away with large volumes of water, resulting in significant quantities of hazardous waste. The process is labor-intensive, dirty, and may overload waste treatment facilities.

Alternatives to solvent/chemical paint stripping techniques which reduce hazardous waste generation require new equipment and facilities. These techniques include plastic media "blast" stripping, laser paint stripping, flash lamp stripping, water jet stripping, and CO₂ pellet stripping. Changes to conventional solvent/chemical stripping have been somewhat successful in reducing the volume of waste generated, but most of the problems involving hazardous pollutants remain.

The more promising developments in the area of paint stripping modifications are summarized below.

Plastic Media "Blast" Dry Stripping

Conventional sand blasting, abrasive blasting, and glass bead blasting have been extensively used for decades to remove paint and rust from metal surfaces. These removal techniques cannot be used in many military applications, however, because the abrasive media can damage aluminum and fiberglass surfaces and small delicate steel parts. Sand and glass blasting can also cause respiratory ailments, such as silicosis. Softer dry media (walnut shells, rice hulls, etc.) has had limited success in replacing sand and glass for various paint stripping operations where hard media could not be used. This "soft media" blasting method has received considerable attention for both military and industrial applications. These natural soft materials are reasonably effective but are susceptible to biological growth during storage and are difficult, if not impossible, to recycle.

Recently a new type of media was developed and manufactured in commercial quantities for blast stripping painted surfaces without damaging the under surface. The media has many advantages over other materials, including engineered abrasive characteristics, and it is recyclable, durable, and non-hazardous. This media is constructed of soft plastic and is formed into rough-edged beads. Old paint is dislodged with conventional sand blasting equipment using the recoverable plastic beads in lieu of sand, and dry waste of pulverized paint and plastic beads is produced. Waste volume is significantly reduced and the waste is more readily disposed of than the wastewater produced in conventional solvent stripping. Currently, only United States Plastics and Chemical Company (a former subsidiary of Koppers, Inc.) manufactures the plastic media. The plastic is available in three material hardness grades (Polyextra,

Polyplus, and Type 3), and six grain size sieve distributions (12-16, 16-20, 20-30, 30-40, 40-60, and 60-80) for use on a wide variety of applications to strip coatings from substrate materials.

Plastic media paint stripping is the most promising alternative to conventional solvent stripping. It has been successfully demonstrated for aircraft renovation at Hill AFB (22, 23) and at Pensacola NARF (24, 25). The process is being considered by many other military installations because of the highly successful demonstrations and testing and its cost effectiveness (25, 26, 27).

Through careful control of the size of the beads and the conditions of the process, the plastic media can be separated from the loosened paint particles and recycled. Generation of wet hazardous waste (solvents and paint sludge in water) is completely eliminated. A small volume of dry waste is produced, which would be classified as hazardous due to metal content.

The two key parameters for successful use of plastic media blasting are hardness and reusability. First, the paint must be softer than the plastic media, which in turn must be softer than the surface underneath the paint coat. Second, the media must be durable enough to be reused over and over to minimize the amount of waste residue which must be disposed of as a hazardous waste.

With some very hard paints (such as epoxy and urethane paints), pre-softening with a solvent (such as methylene chloride) was used before plastic media stripping. Recent test information, provided by the media supplier, indicates that these paints have been successfully removed after modifications to media selection and application methods. The modifications eliminated the need for pre-softening of the paints.

The plastic media blasting technique has been shown to be effective in stripping and removing a variety of coatings from a number of substrate surfaces. However, extreme care must be exercised on composite surfaces, thin-skinned aluminum, and other fragile materials. In particular, problems with unravelling of composite fibers have been encountered in blasting composite surfaces that do not have a resin-rich surface. In some instances, using excessive pressure and/or holding the nozzle too close has resulted in surface damage. Even though the process is relatively simple, considerations such as these make it imperative that adequate training of operators be provided.

The blasting action helps to stress-relieve surfaces while removing paint from titanium, stainless steel, alclad, and anodized aluminum. Alclad aluminum surfaces have a sand-blasted appearance after blasting because the soft aluminum clad is softer than the plastic compound. This soft aluminum coating is moved, but not removed, and in fact presents a much better surface for repainting.

Many additional applications will be realized as developmental testing in the military and industry continues. Table 3-3 lists some of the coatings and substrates successfully stripped with plastic media (36).

Table 3-3
APPLICATIONS OF PLASTIC MEDIA BLAST PAINT STRIPPING

Coating	Substrate	Application
Polyurethane	Aluminum	Aircraft fuselage
Epoxy polyamide	Alclad aluminum	and components
Acrylic lacquer	Anodized aluminum	Components
Enamel	Steel	Ship bilges
Fluorocarbons	Magnesium	Vehicle bodies
Metallic spray	Anodized magnesium	Boat hulls
Koropon primer	Titanium	Engine components
Rain erosion	Carbon graphite	Truck wheels
Fuel sealants	Fiberglass (except	Propeller blades
Structural adhesive	Radomes and Kevlar)	Molds
Corrosion buildup	Honeycomb	Heat exchangers
Lubricants		Alloy fuel tanks
Polysulfide sealants		
Carbon buildup		

The potential economic savings associated with plastic media stripping are substantial. The estimated savings in labor, chemicals, and waste treatment/disposal amount to over \$100 million annually (26). Additional savings in energy, compliance costs for future environmental regulations, and productivity are likely to be equally significant. The preliminary cost estimate presented in Table 3-4 illustrates the potential savings.

The plastic media paint removal process is so simple and efficient that it lends itself to a wide variety of uses, both military and civilian. Its most notable feature, however, is the fact that it almost entirely eliminates pollution and toxic waste. The only waste product of this system is a comparatively small amount of dry fine plastic dust and paint particles containing trace heavy metals from the

Table 3-4
ANNUAL SAVINGS COMPARISON FOR ALL
DOD FACILITIES--PRELIMINARY ESTIMATE

<u>Item</u>	<u>Solvent/Chemical Stripping</u>	<u>Plastic Media Stripping</u>
Labor and material		
Manhours	3,360,000	hr
Solvents/chemicals	7,000,000	gal
Wash water	100,000,000	gal
Wastes	107,000,000	gal
		500,000 lb dry
Operating costs		
Manhours	\$136,516,800	\$67,698,380
Material supplies	30,960,000	4,400,000
Waste treatment and disposal	<u>8,000,000</u>	<u>1,500,000</u>
Total operating costs	<u>\$175,476,800</u>	<u>\$73,598,380</u>
COST SAVINGS		<u>\$101,878,420</u>

paint. This waste is easily contained within sealed drums and can be safely transported for disposal or storage. There is no liquid waste generated, and because the air system is self-contained and dust removal facilities are provided, there is no air pollution. The plastic media is recycled and used with very little loss by degradation. Energy, materials, labor, and product efficiency are all significantly less costly than in conventional solvent paint stripping operations. Personnel protection required includes ear plugs, goggles or masks, and filtered breathing air to protect from the paint dust.

Wet Media Stripping

Wet media stripping is similar to conventional hard media blast cleaning except water instead of air is used as the carrying fluid. Wet blasting is a precision finishing operation and is usually conducted in cabinets on small items. This process is not considered applicable for military equipment applications.

Solvent Reuse and Waste Reduction Techniques in Conventional Solvent Stripping

Several waste reduction techniques have been demonstrated or are practiced by the military and industry (1). These techniques are generally non-technical, labor-intensive methods

to reduce the volume of hazardous liquids and wash waters generated.

At Norfolk NARF, paper is placed on the floor of the paint stripping hangar to collect the loosened paint and spent stripper solution. This dry technique has eliminated the high volume of solvent-laden wastewater normally produced in such a facility. The reduced volume of waste is then incinerated.

Stripping solvent reuse has been investigated at Hill AFB to reduce waste generation. Laboratory testing was conducted on filtering paint particles from collected solvent/paint residues. In theory, the filter solvent stripper could be reused. Initial tests showed some loss of stripper characteristics, which probably could be overcome by adding makeup chemicals. The major problem of collecting the stripper/paint residue without using either water or significant hand labor was not solved. A full-scale solvent reuse system could save \$60,000 per month at Hill AFB if a cost-effective method were found to collect the solvent/paint residue.

Industry has approached reducing wastes in similar ways--using labor-intensive methods to collect solvent/paint residue in concentrated form, thereby minimizing the volume of hazardous wastes and wash waters generated. Pan American Airlines at JFK Airport in New York uses aluminum troughs taped to the side of the aircraft to collect stripped solvent/paint residue and convey it directly into 55-gallon drums. This minimizes wash water use, thus decreasing the waste volume. Plastic troughs and sheets beneath aircraft have also been used to collect stripping water and minimize the use of wash water for cleanup. Extensive use of manual squeegees to remove the maximum amount of stripper before washing is another common practice.

Other common methods of eliminating onsite waste generation include using contractors (moves the problem from one place to another), not using paint, and using decals that are easily removed.

The present practices to reduce waste production in conventional solvent/chemical paint stripping operations generally have limited benefits, but may be very effective in certain applications. The major problems associated with solvent/chemical strippers are, for the most part, not solved. Solvent air emissions remain at the same levels because the solvent use is basically the same. Lower volumes of more concentrated solvent wastes are produced but still the amount is considerable and probably even more hazardous to handle because of the high concentrations. Wash water is still required for final surface washing and though the concentrations of contaminants are lower, the wastewater must still be treated to meet local discharge limitations.

Advanced Paint Stripping Alternatives

New advanced paint stripping technologies are continuing to be developed by industry and the military for specific special applications in the interest of increased productivity, lower costs, and reduced waste generation. These advanced technologies are in the R&D stage or are used only for special applications and have not yet been implemented in general commercial applications. They may prove to be viable alternatives in the future; therefore, a brief process description for each is provided.

Laser Paint Stripping. In the Air Force's testing of lasers for removing paint, research has been directed at the development of a pulsed CO₂ laser system. The pulsed laser was used to minimize energy consumption, while the CO₂ was selected because its wave length is readily absorbed by paint. Actual pilot-scale tests showed the paint material was completely removed from test surfaces. The system, in which a full-scale operational installation would be based on a robot-operated pulsed CO₂ laser, is still very much in the experimental stage. Although this alternative appears to be technically feasible, there are many unknown factors involving system reliability, effects on aircraft substrate and components (electronics, sensors, etc.), air pollutants, and so forth that need extensive R&D work. It may take 10 years or more for this technology to be commercially available. In addition, by one estimate, the initial capital outlay for a fighter aircraft-size facility with automated laser system would be at least \$10 million, which is an order of magnitude greater than a comparable plastic media blasting facility.

Flash Lamp Stripping. Flash lamp stripping is similar to stripping with laser light, but uses high energy quartz lamps to vaporize paint. The Air Force is conducting R&D on this process. Unlike laser stripping, flash lamps have been demonstrated not to harm aircraft electronics. However, this technique is difficult to operate, requiring extensive operator training. Questions which still need to be resolved involve potential damage to various substrates, generation of toxic air pollutants, and design issues regarding a production unit. In Navy tests this method failed to remove barnacles from the bottom of ships, and produced loud, annoying "bangs" when operating.

Dry Ice Blasting. Dry ice blasting was investigated by the Lockheed Company for removing aircraft paint (2). Dry ice or CO₂ pellets were used as a blasting media. The attractive aspect of this technology is that CO₂ pellets vaporize after being used and the only waste product is the dry paint chips. There are, however, questions concerning the potential damage to the aircraft's surface, how well this method will remove paint, and operation costs. Additional R&D on this technology is on hold.

Cryogenic Coating Removal. This method operates on the principle that organic coatings become brittle and tend to debond from substrate metals because of differential thermal contraction of the coating and the substrate metals at low temperature. Small cabinet-size equipment based on cryogenics is commercially available. Liquid nitrogen is sprayed on the coating to lower the surface temperature to -100°F and plastic media is mechanically thrown at the surface to break off the frozen paint (28). This system is not suitable for large-scale operations.

High Pressure Water-Jet Blasting. Water-jet blasting for removing paint was recently investigated by both the Air Force and the Navy. Pulsed or continuous water-jet blasting created through high pressure pumping was used to remove paint. As with the other systems discussed, the use of a water-jet is technically feasible; however, questions on the system's control and reliability, potential damage to the aircraft's surface, ability to remove a wide range of coatings, and worker safety need to be resolved.

Salt-Bath Paint Stripping. Equipment is commercially available to strip paints in molten salt baths operating at a temperature of 900°F (28). This method is practiced in the automotive and appliance manufacturing industries. In this process, items to be stripped (normally steel) are immersed in the molten salt bath (mixture of sodium hydroxide, sodium or potassium nitrate, sodium chloride, and catalysts). This process is not applicable to most military applications because it cannot be used on the materials military equipment is constructed of--mainly aluminum, nonmetallics, and alloys.

Burn-Off Systems. High temperature flames, ovens, and fluidized beds are commercially used to literally burn the paint off--mostly from steel surfaces. This technology is not applicable to most military applications because its use is limited to steel parts (28).

Hot Caustic Strippers. Hot caustic solution stripping is commercially practiced by industry, and equipment is readily available. Hot caustic baths, typically at temperatures over 200°F, are very effective in removing caustic-sensitive paints. Many of the coatings used by the military, such as epoxies, are both caustic and heat-resistant. This system is also limited to steel parts because the caustic corrodes many materials, including aluminum. This technology is not applicable to most military operations (28).

3.3.2 Painting Modifications

Alternatives to conventional solvent-based spray painting which reduce hazardous pollutants require an integrated approach whereby painting techniques are improved and processes that reduce or eliminate hazardous materials are used.

For example, modifications to painting techniques can minimize the amount of wasted paint that ultimately must be disposed of as hazardous waste. Also, paint formulas can be used that minimize or eliminate solvent paint thinner and clean-up solvents, both of which contribute to hazardous waste and air pollution problems. In addition, substitution solvents may be used to minimize air pollution and produce less toxic hazardous waste.

The more promising developments in the area of painting modifications and substitutions are summarized below.

Powder Coating Techniques

Powder coating technology, also called "dry powder painting," is one of the major advances in the application of coatings. This technique is based upon the deposition of specially formulated thermoplastic, or thermosetting, heat fusible powders on metallic substrates. Since no solvents are used in the system, the pollution and safety problems associated with solvent-based paints are eliminated. Also, air emissions of VOCs are almost completely eliminated, clean-up solvents are greatly reduced, paint thinners are eliminated, and there is no waste (old) paint to dispose of (14). In addition to the environmental advantages offered by dry powder painting, the process provides technical, production, and cost benefits. Productivity is increased because, without solvents, the coating can be cured immediately after application, and because curing is thermoactivated, curing times are short. A technical advantage is that special coating materials, which cannot be applied by conventional solvent-based systems because of the lack of surface solvents, can be applied by dry powder painting. In addition, complex surfaces are more evenly coated in dry powder systems and for some applications, a single coating can replace multiple coating applications used in conventional spray painting. Dry powder techniques are also readily adaptable to current production methods and are easily learned by painting personnel.

The one major limitation in dry powder painting is that the items to be painted must be able to withstand the typical curing temperatures of 350°F for 30 minutes (15). Aluminum alloys cannot be subjected to these conditions without significant loss of strength.

Commercially available dry powder painting techniques are electrostatic dry powder painting, the fluidized bed method, and plasma spraying. A description of each follows.

Electrostatic Dry Powder Painting. This is the most widely used powder coating technique. In this method dry powder sprayed onto the surface, where it is electrostatically

deposited. The dry powder is metered into a compressed air driven spray gun and sprayed at the surface. An electrode in the spray gun ionizes the air/powder suspension using direct current and the dry powder particles become charged. The surface to be coated carries the opposite charge and the powder is electrostatically attracted to the surface. Coating thickness is limited by the loss of attraction of the powder to the surface as the coating builds up--resulting in very uniform coating thickness even on complex shapes. The coating is then fused to the surface and cured in conventional ovens.

In commercial applications, the powder overspray is collected in conventional air filter systems and is reused, thus eliminating disposal of overspray water associated with liquid solvent-based paints. Powder utilization of 90 to 99 percent is possible. Table 3-5 compares annual operating costs of powder and conventional solvent painting systems. The basis for comparison is facilities required to coat 12,000,000 square feet of parts with a 1 mil polyester coating (14).

Table 3-5
COMPARISON OF SOLVENT PAINTING
TO POWDER PAINTING

Item	Conventional Solvent	Dry Powder
Material	\$333,600	\$242,400
Labor and cleanup	132,100	75,600
Maintenance	18,000	10,000
Energy	29,100	15,700
Hazardous waste disposal	10,800	1,100
Total annual cost	\$523,600	\$344,800
Cost per square foot	\$0.044/sq. ft.	\$0.029/sq. ft.

Fluidized Bed Method. This technique is typically used for applying relatively thick coatings (10 to 60 mils) to small objects (16). In the fluidized bed method a dense cloud is created by passing air through a powder reservoir to create a suspension of powder that behaves like a fluid. The part to be coated is preheated and immersed in the fluidized powder, where the powder fuses to the part. The coated part is then cured in a conventional oven.

Plasma Spray. This technique is relatively new and still mostly in the developmental phase. Dry powder is fed into an extremely hot (5,000 to 15,000°F) gas stream where the hot gas melts the plastic and forms a plasma of gas and plastic. The residence time of the powder in the gas is

very short to prevent material decomposition. The plasma stream is sprayed onto the substrate where a dense, pore-free coating forms as the paint material condenses. The advantage of this system over other dry powder techniques is that the coating is applied and cured in one step, eliminating the need for subsequent heat treatments. Since the substrate surface temperature does not exceed 185°F, this coating system can be used on substrates that are heat-sensitive. For example, tests have shown that 7075-T78 aluminum alloy was not affected when painted by the plasma technique while a 10 percent tensile strength loss occurred with a curing temperature of 255°F (16). The plasma technique can also be used for items too large to be cured in conventional ovens. Personnel protection would be required due to the high temperatures produced in the spray.

Wet Electrostatic Painting

Wet electrostatic painting is similar in theory to deposition of dry powder coatings by electrostatic attraction. It differs in that some solvent is used as thinner (the solvent content is lower, however, than in conventional spray painting). Overspray is minimized if not eliminated, resulting in hazardous waste reduction. Wet electrostatic painting is widely used for painting aircraft parts and other small, complex, non-aluminum metallic articles. There is, however, concern over the potential safety hazard of imparting high voltage to an aircraft which may still contain fuel vapors.

Electrocoating

Electrocoating is similar to metal plating and is commonly used in automotive body coating. In this process, metallic or other electrically conductive parts are dipped into a solution which contains specially formulated ionized paint. The action of an electric current induces the paint ions to deposit on the part. The paint formulations are a special class of waterborne nonvolatile organic compounds. Hazardous waste production is minimal, and VOC air emissions are almost eliminated. One limitation inherent in this process is the requirement for dip tanks, which limits the size of items that can be painted. A more important disadvantage is that the system can only be used to apply one coat (a prime coat or a single finish coat) because the coated surface prevents further electrodeposition (17).

Waterborne Coatings

Waterborne coatings are used extensively in industry and on a limited basis by the military. In waterborne coatings (as the term suggests) the carrier solvent is water rather than an organic solvent. Hazardous pollutant generation is less

with the waterborne paints compared with solvent-based paints. The most significant decrease is in VOC emissions, which are almost eliminated in waterborne painting, through a reduction in solvents and use of compliance solvents. In addition the use of solvents for cleanup is greatly reduced and no solvents are needed for paint thinning. Wastewaters generated from waterborne painting contain less toxic organics because of the limited solvents in the paint. In industry, waterborne paints are normally used in applications requiring only moderate protection and where decorative requirements are of prime importance. Waterbornes are extensively used for decorative/protective coatings on metallic surfaces as well as non-metallic surfaces such as hardboard, wood cabinetry, and plastics (18).

For military applications, there are two key disadvantages of waterborne paints. First, the surface must be completely free of oil type films or the paint will not adhere well; this is a problem at most military installations. Second, waterborne coatings require longer drying times or even oven drying in cold/humid weather; this requirement may result in significant expenses to outfit an installation for waterborne paints (19).

Positive results with water-based primers have been achieved in applications where conditions were acceptable. At NARF Pensacola, waterborne primers are being tested with the goal of substituting them entirely for existing solvent-based primers. The waterborne primer selected is a water-reducible, amine-cured, epoxy primer manufactured by Deft Chemical Industry, Inc., which meets Navy specification MIL-P-85582, (for aluminum substrate), and Army specification MIL-P-53030 (in steel ordnance). This waterborne paint does contain some compliance solvent, but less solvent than actual solvent-based primers. The paint's volatile fraction contains approximately 80 percent water and 20 percent solvent. In addition to reducing solvent emissions and wastewater discharge, cleanup is performed effectively using hot water.

High-Solids Coatings

High-solids coatings, which are similar in composition to solvent-based coatings, are becoming more widely used for some industrial applications. High-solids coatings contain about 25 to 50 percent solids and, compared to solvent-based coatings, use lower molecular weight paint resins with high reactive sites to aid in coating polymerization. The finished coat is comparable to normal solvent-based coatings. The high-solids coatings require special spray equipment for application because of the higher viscosity. Because less solvent is used, less is available to wet metallic surfaces contaminated with oils; therefore, surface preparation is

more critical. Spray application is also more difficult because there is a tendency to apply too much coating to achieve a similar "wet" appearance obtained in normal solvent coatings. The general opinion in the industry is that high-solids solvent-based coatings will become the "standard" to replace normal solvent-based coatings. The major advantage will be the capability to comply with the more stringent VOC limitations while using the same basic paints, equipment, and application techniques (20).

Improved Painting Techniques

There are many techniques that can improve product quality, increase production rates, and reduce the generation of hazardous wastes with only minimal changes in equipment and procedures. The most promising techniques to improve painting which also reduce hazardous wastes are discussed below.

Airless Spray Application. This method can be used for most applications where air spray is used. Airless sprayers have 20 to 30 percent better transfer efficiency than air spray, resulting in less overspray waste to dispose of and lower VOC emissions. The disadvantages are a coarser finish and a higher paint flow rate, requiring better paint application control.

Air Assisted Airless. This technology combines the best characteristics of both air and airless spray (21). It uses an airless fluid spray tip to atomize the coating into a fan pattern at moderate pressures, and a second low pressure air stream is added just after the nozzle to improve atomization and spray pattern. This new system is reported to provide the finish control of air spraying with less overspray and higher transfer efficiency than airless spray.

Conveyor Systems. These can be operated to maximize painting efficiency while minimizing hazardous waste generation. At one installation, Lockheed-Georgia Company uses a modern conveyor system to paint small aircraft parts. Paint personnel spray parts as they move along the conveyor system, allowing parts to be plated, painted twice, and oven-cured if necessary, all without being touched. The system has provided improved product quality, since impurities from handling are eliminated; in addition, operators can concentrate on improving painting technique, which has reduced overspray and excess paint use. Overall, the system is more efficient and produces less hazardous waste from overspray and cleanup.

Robotics. This technology has tremendous potential for hazardous waste reduction both in painting and paint stripping applications. Not only could overspray and spills be reduced, but the higher temperatures required for application of "low" and "no" solvent formulations could be

Work Platforms. Specially designed, wheeled work platforms have been built to provide access to all surfaces of an aircraft or other equipment being treated. The wheels are sized to operate over the floor grating and include locking mechanisms. These platforms include floor grating of industrial grade and all the proper handrails. Where the frame of the work platforms may come in contact with aircraft surfaces, the structure has been covered with thick rubber cushions to prevent damage to these surfaces.

Figures 3-2 through 3-11 are photographs that illustrate the operation of the bead blast facility at Hill Air Force Base.

Recommendations for Standard System

In order to reproduce the blasting booth facility at other locations, it will be necessary to put together a complete engineering package consisting of engineering drawings for all disciplines, engineering and equipment specifications, as well as installation and operating instructions.

It is recommended that the system be engineered as a fully complete, independent module that can be used in any combination to suit production requirements or site conditions without the need for additional engineering. One module or combination of modules thus would suit all requirements, and the integrity of the blasting process would be maintained. The blasting booth at Hill Air Force Base is recommended as the model for the single-booth module. This module is sized for one fighter-type aircraft and its disassembled parts; two modules back to back sharing the same equipment room would service two aircraft simultaneously (see Figure 3-12). Two of these tandem units side by side would service four aircraft simultaneously with the equipment room still central to the whole facility (see Figure 3-13).

In order to service a larger aircraft, e.g., a multi-engine air tanker or similar size aircraft, four or more single modules could be used with the live floor sections adjacent to one another, and the equipment rooms located on the sides of the building (see Figure 3-14).

By establishing a standard engineering package, standard costs could be set within an acceptable range which need not be exceeded no matter where the facility is built. Such a package would promote cost control and help avoid costly "add-ons" of equipment and processes that would not significantly improve the blasting process. For the military, this would provide a measure of assurance that the exact system needed would be provided without deviation, over-runs, and delays. A "turnkey" contract to provide a facility (and initial training) could be used.

damaged. The floor dust collection troughs are steeply sloped to provide good material flow and are protected by the floor's supporting members. These troughs are covered by fine wire mesh screens to catch oversized debris or discarded "trash" and prevent plugging of the "drawdown" holes at the bottom of the troughs. The entire live floor trough system is covered by standard grating in panels sized for easy manual removal.

The live floor system covers the entire floor area of the blast booth, wall to wall. The floor's air duct system is designed to provide equal suction force over the entire floor area. This enables simultaneous blasting areas to be used throughout the booth, under normal blasting pressures, without any loss of suction force in any particular area. This system prevents the occurrence of "dead" areas, a feature not found in other live floor air systems.

The live floor was installed on top of a custom built concrete floor but could easily have been installed on top of an existing hangar floor. The live floor structure is only 6 inches deep. If mounted on an existing floor, shallow ramps would have to be poured from existing grade to the top of the live floor.

Bead Recovery and Storage. The live floor plenums are connected by ducting in the equipment room to the vacuum equipment and the dust collection and separation system. The dust separation and collection equipment is located outside the building and consists of screening equipment mounted on top of a dust collector. The reclaimed plastic beads are returned to the bead storage hoppers via steeply inclined chutes through the wall of the building. The collected paint particles, spent plastic media, and dust are discharged from the bottom of the dust collector hopper into sealed drums outside the building.

The plastic bead storage hoppers are located inside the equipment room and are mounted above the blasting system machines. The blasting system consists of five Paulli and Griffin 10 cubic foot vessels, each with its own set of controls and gauges which can be preset and locked. Each vessel is connected to header pipes running along the north and south walls of the blast booth. There are five separate and independent blasting hoses, each having a half-inch nozzle, strategically placed to cover the entire blasting area.

A single 100-hp air compressor supplies the blast air to all five blasting machines and enables a blasting pressure of 40 psi max to be maintained at each of the five nozzles. Make-up air is filtered and dried. The weight of each of the blasting hoses is carried by overhead counter-weighted mechanisms to reduce operator fatigue, to keep the hoses from dragging on the deck, and to keep them clear of the equipment being blasted.

divided into two separate areas, both totally enclosed and insulated. One area is the blast booth itself, and the other (smaller) area is the equipment room. The blast booth has four doors. The main access door, which spans the entire width of the booth, is located on the west end; it is a standard horizontal hinged split overhead hangar type door. The south side of the booth has a standard overhead roll type door for equipment access and a standard personnel access door. Adjacent to it is a similar personnel access door on the north side of the booth. Each of these doors is connected to a warning device consisting of a red strobe light mounted at the ceiling which will be activated in the event that someone enters the booth during blasting. The opening of any one of these doors will also automatically shut down the blast air supply to the nozzles.

Fire protection in the blast booth is provided by a halogen gas suppression system mounted at the ceiling. Because the blasting and reclaim system is a dry operation, a water sprinkler type fire suppression system could not be used.

Lighting in the booth is supplied by 12 lights, recessed into the booth walls, as well as overhead lighting which eliminates most shadows.

The blast booth includes a suspended ceiling and finished internal walls to minimize the buildup of dust. Due to the downdraft nature of the recovery system (live floor and overhead return air), very little dust should be suspended in the air. Because the dust is of an inert material, air flow and dust level monitors should not be required in this facility, and have not been included. This equipment could easily be added at a later date.

The equipment room takes up about one-fifth of the building and is located at the east end. It is completely isolated from the blasting area; no access doors between the equipment room and the blasting area are provided. This design is intended to prevent ingress of dust into the equipment room and inadvertent access to the blast area by untrained personnel who may be working in the equipment room. A control/observation room has been built in the area dividing the blasting area and the equipment room, with the access door inside the equipment room. This room should allow for safe observation of the blasting procedure by visitors, and provides space for supervision of the blasting without having to enter the blasting area.

Floor System. The facility is constructed with a live floor system that collects blasted plastic media, paint particles, and dust. The structural elements of the floor were built into the integral ducting system and were fabricated in standard sized module sections to facilitate removal if

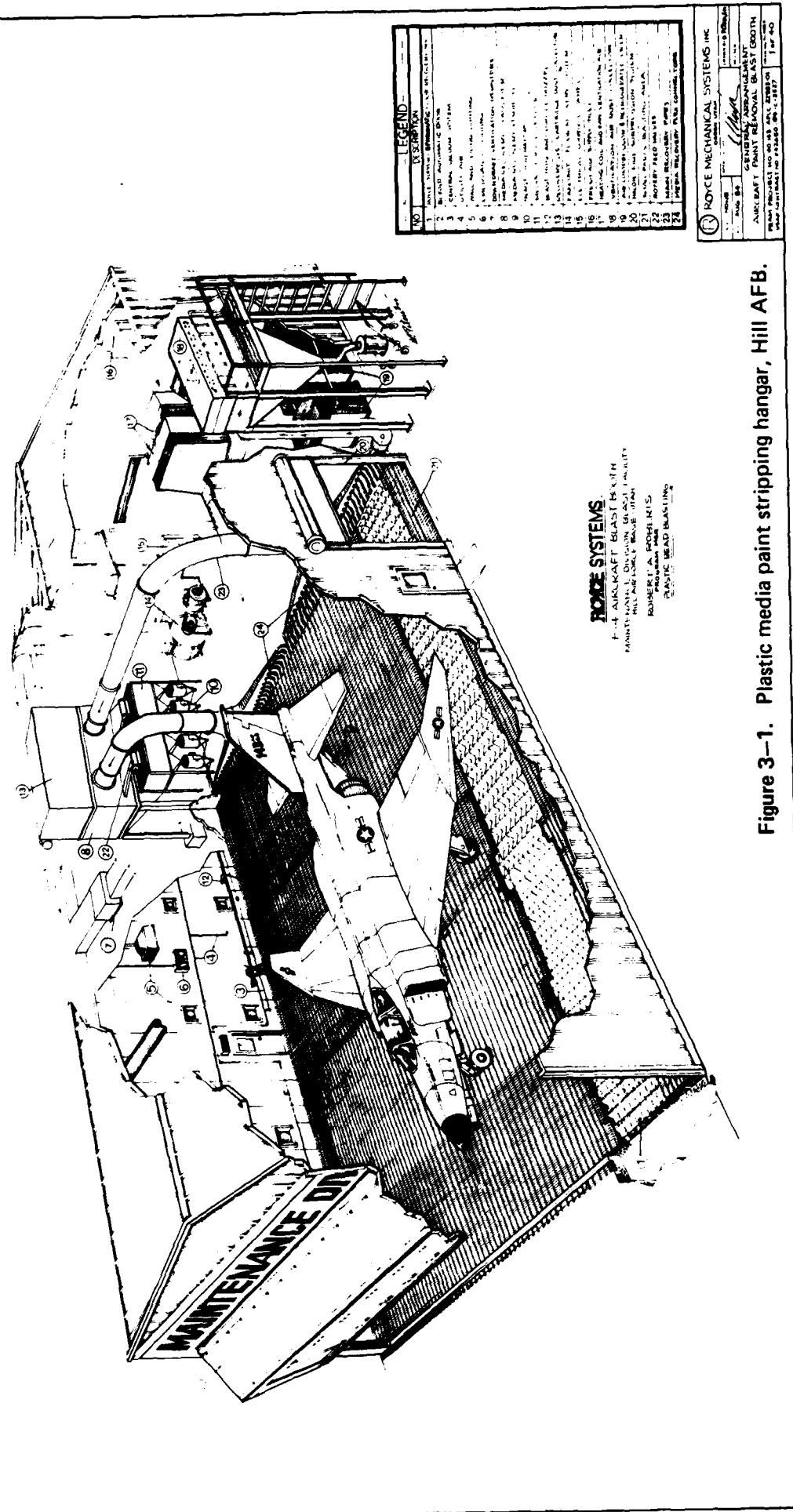


Figure 3–1. Plastic media paint stripping hangar, Hill AFB.

Flow Days. Plastic media stripping decreases the overall time needed to renovate aircraft for use; therefore utilization of aircraft is increased. Plastic media stripping requires 1/2-day, compared to 3-1/2 days to complete the solvent stripping process. Based on USAF Cost and Planning Factors, AFM 173-3, the flow day efficiency cost savings amount to \$1,353,210 annually.

Building 223 Hill AFB - PRAM Plastic Media Paint Stripping Facility

The new plastic media stripping facility (also called "blast booth") at Hill AFB Building 223 is a full-scale plastic media aircraft stripping facility specifically constructed for F-4 aircraft maintenance. Construction of the facility is the third stage of the three-stage PRAM (Productivity-Reliability-Availability-Maintainability) project 00-143. Stage 1 tested plastic media removal of paint from aircraft component parts. Stage 2 was planned to involve removal of paint only from aircraft leading edges but was changed to full prototype F-4 aircraft plastic media stripping (conducted at Building 236) so that development of the process could be accelerated. Stage 2 testing included stripping of entire aircrafts with all components (including engines) in place as well as partially disassembled aircraft. Stage 3 is the full-scale production aircraft stripping, based on all the information gained in the first two stages, which is scheduled to be completed concurrent with the PRAM blast booth construction.

The major components of the plastic media paint stripping facility are shown in Figure 3-1. Bob Roberts, Program Manager, spearheaded the facility's design and construction. Royce Mechanical Systems, Ogden, Utah, provided fast-track component design and facility construction. The facility includes a steel prefabricated insulated building (45 ft x 75 ft x 25 ft high) and all process and support mechanical and electrical equipment. Total facility cost, including equipment and labor, is \$647,389. The facility cost payback will be just over one month based on operation cost savings.

Plastic media is entrained in a compressed air stream and is blasted on to the painted surface through a nozzle via pipe and hoses. The paint residue, dust, and plastic media fall through a grated floor and are collected in vacuum suction ducts. Screens and filters are used to separate the paint residue and dust from the plastic media. The paint/dust residue is collected in a hopper which empties into sealed drums for disposal. The plastic media is then returned to storage and is ready to be used again.

The building which encloses the blasting booth is spacious and provides an adequate working area. The building is

Table 3-9
PRODUCTION COMPARISONS AT HILL AFB

<u>Item</u>	<u>Solvent Strip Time</u>		<u>Plastic Media Strip Time</u>
F-4 Component:			
Rudder	3 hr	36 min	15.6 min
INBD L/E Flap	2 hr	48 min	21.6 min
Spoiler		40 min	14.4 min
OUTBD L/E Flap	2 hr	48 min	18.6 min
Aileron	6 hr	28 min	32.4 min
Wingfold	8 hr	45 min	54.1 min
Stabilator	9 hr	49 min	55.2 min
Aircraft and Equipment:			
F-4 (Prototype)	341 hr		39 hr
F-100 (Museum Aircraft)	290 hr		25 hr
P-8 Pumper (Fire Truck)	52 hr	(sanding)	4 hr
D-50 Pickup (Compact)	40 hr	(sanding)	1 hr 20 min
1/2 Ton Pickup (Full size)	60 hr	(sanding)	1 hr 55 min

Energy. Two components make up most of the energy use in stripping: the energy required to maintain the building interior at the required temperature and the energy required to operate equipment electrical motors. Solvent stripping operations require significant energy to heat the building because the building interior air must be maintained at 72°F ± 2°F for proper solvent action on the paint, and large fresh airflows are required to ventilate the solvent vapor emissions. These annual heating costs are \$201,600 (Basis: 507,000 CFM fresh air, average annual temperature 51°F, 16 hr/day at 260 days/year building use, steam cost \$5.59/million Btu's). Solvent stripping mechanical equipment also requires significant electrical energy to operate. The annual electrical energy cost is \$49,634 (Basis: 320 motor hp, 16 hr/day--260 days/years equipment use, \$.05/kWh electrical energy cost). Plastic media stripping operations require much less heating and equipment electrical energy. Almost no building heating is required because the waste heat generated from the air compressor equipment used in blasting plastic media generates sufficient heat to heat the building. And, since no solvents are emitted into the air (which would have required large fresh air flows), no significant amount of heat for fresh air is needed. Plastic media stripping equipment electrical energy requirements are also much less than those of solvent stripping equipment. The plastic media equipment requires only \$27,305 in annual electric energy costs (Basis: 340 motor hp, 8.25 hr/day--260 days/year, \$.051/kWh electrical energy cost). Therefore, plastic media stripping operations will result in \$223,929 annual energy costs savings.

probably contribute a higher percentage of sludge in proportion to the flow from this source. This is probably not too high an over-estimate, due to the large amounts of coagulants typically used for industrial wastewater treatment, which are applied proportional to flow and whose products form a major portion of the sludge produced.

Water Pollution. Thirty-five percent (210,000 gal/day) of the 600,000 gallons per day of wastewater treated in the on-base industrial waste plant is generated from the solvent stripping operations. About 20,000 to 30,000 gallons of water is used to wash off the stripper and paint residue for each stripper application. Several applications of stripper are normally required. Water is also used to wash floors and general area maintenance, all of which contributes to the wastewater flow. The annual cost of treatment chemicals at the industrial waste plant is \$912,500. Reducing the waste flow by 35 percent is estimated to reduce treatment chemical use proportionally and save \$319,375 annually. Additional savings in operation and maintenance expenses, such as labor, equipment repair and replacement, for the industrial waste plant were estimated to be \$207,000 annually. Thus, the total estimated annual chemical and operation and maintenance cost savings are \$526,375.

Materials. Solvent stripping F-4 aircraft requires 468 gallons of chemical stripper at a cost of \$11.40/gallon and uses 12 rolls of aluminum masking tape at a cost of \$7.30 per roll for a total cost per aircraft of \$5,422 (\$1,165,902 annual cost). Plastic media is recycled, but losses occur due to abrasion of the media. Media loss is estimated to be 200 pounds per aircraft at a cost of \$1.73 per pound, for a cost per aircraft of \$346 (\$74,390 annual cost). Savings per aircraft amounts to \$5,076 or \$1,091,340 in annual savings.

Labor. Labor savings is one of the most significant advantages media stripping has over solvent stripping. Solvent stripping F-4 aircraft requires 341 labor hours per aircraft, at a labor rate of \$33.56 per hour, for a cost per aircraft of \$11,444 (\$2,460,460 annual cost). Plastic media stripping is estimated to require 39 labor hours per aircraft, at the same \$33.56 per hour labor rate, for a cost per aircraft of \$1,309 (\$281,400 annual cost). The annual labor cost savings is estimated to amount to \$2,179,060 for F-4 aircraft alone. Additional significant labor savings are expected when plastic media stripping is used for other aircraft and equipment that is currently stripped using solvents and other conventional methods. Typical prototype production comparisons for F-4 aircraft components and estimated production comparisons for other aircraft and equipment are shown in Table 3-9.

Table 3-8
SAVINGS COMPARISON
PLASTIC MEDIA VS. SOLVENT PAINT STRIPPING

<u>Item</u>	<u>Savings</u>	<u>Annual Cost Savings</u>
Hazardous waste	Generates 1/100 the waste sludge which requires hazardous waste disposal	\$ 218,000
Wastewater pollution	Eliminates generation of 210,000 gallons per day of wastewater which must be treated in on-base waste treatment plant before discharge to the City municipal treatment plant	\$ 526,375
Materials	Eliminates the use of chemical solvents and requires minimal use of plastic media to make up for worn-out media	\$1,091,340
Labor	Requires 1/10 the labor	\$2,179,060
Energy	Requires 1/10 the energy	\$ 223,929
Flow Days	Provides increased flow day utilization of aircraft	\$1,353,210
TOTAL ANNUAL SAVINGS FOR 215 F-4 AIRCRAFT		\$5,591,914

The wastewater containing solvent and paint residual generated from solvent stripping F-4 aircraft is estimated to contribute 35 percent of the total sludge produced from Hill AFB. Therefore, total sludge contributed by solvent stripping is 1,050 tons. The only hazardous waste produced by plastic media stripping is the dry stripped paint residue, which amounts to 120 lb per aircraft and the dry spent plastic media, which amounts to 200 lb per aircraft--only 34 tons per year. The savings in hazardous waste products is 1,016 tons annually, a 99.9 percent reduction, and \$218,000 in annual savings. This savings is probably over-estimated because it assumes that sludge production is proportional to flow. Metal plating operations on the base

an F-4 aircraft, the labor requirements are reduced from 341 hours to approximately 39 hours. This time was reduced to 25 manhours for paint removal on two F-4 aircraft at the recently completed blast booth hangar. Additional personnel hours are required to maintain the plastic media systems equipment, but the amount is estimated to be small and may very likely be offset in reduced personnel hours required to handle the wastes.

Other significant advantages favoring plastic media stripping compared to conventional solvent stripping include approximately 50 percent less energy use in heating, ventilating, and mechanical equipment. Also, overall production capacity is greatly increased, resulting in less time spent rebuilding aircraft, which in turn translates to increased availability. It is estimated that all F-4 aircraft entering the facility in the future can be stripped. In addition to aircraft, the plastic media facility can be used to strip paint from many types of equipment. For example, pickup trucks are stripped in less than 2 hours without masking glass, chrome, and rubber surfaces. Other applications for which prototype production estimates have been made are P-8 pumper trucks, Coleman tractors, and F-100 aircraft.

There are limitations to the plastic media stripping method, but in all cases these limitations are far less severe than those of the present chemical methods of paint removal. For example, stripping of rain erosion coating from radomes using dry media stripping has not been successful; in addition, problems have arisen in removing paint from carbon composite surfaces, fiberglass, and light weight aluminum surfaces without damage to the substrates. Stripping of these surfaces requires an experienced operator using reduced pressures, greater standoff distance, and extreme care to prevent damage. Especially hard to strip are composite surfaces that do not have resin-rich surfaces. In addition, soft cadmium coatings on screws can be removed and plastic windows cannot be blasted.

Estimated savings for plastic media compared to solvent paint stripping based on initial prototype testing at Hill AFB are summarized in Table 3-8. The quantity and cost savings estimates are based on stripping 215 F-4 aircraft annually. These estimates were prepared by Bob Roberts of Hill AFB.

Data and Assumptions Basis for Table 3-8

Hazardous Waste. The existing wastewater treatment plant produces approximately 3,000 tons per year of 10 percent solid weight sludge which is hazardous. The sludge is transported by truck to California, where it is disposed of at a licensed hazardous waste disposal site for a total cost of \$200/ton.

beads in lieu of sand. This new technological achievement has been made possible by the development of new engineered plastic media abrasive material which removes the paint without damaging the substrate. In January 1979, Hill AFB began research and development work to investigate and test alternative media stripping techniques. The program was managed and directed by Bob Roberts. In July 1983, the new commercially produced plastic media was tested with very favorable results. The development program proceeded on a fast-track schedule to construct a full-scale operational plastic media paint stripping facility, with funding approval and design culminating in a turn-key design construction contract award to Royce Mechanical Systems (local Ogden firm) in January 1984. Completed facility operational testing was conducted the first of May 1985 with very successful results.

Comparison of Chemical Stripping Versus Plastic Media Stripping

Plastic media operations generate significantly less hazardous wastes and wastewaters compared with conventional solvent stripping and produce almost no other environmental pollutants. The dry paint residue generated in plastic media operations is one-hundredth the amount of the wet chemical sludge produced from solvent stripping. For an F-4 aircraft, at Hill AFB, the comparative amounts are estimated to be 9,767 lb of hazardous sludge from solvent stripping and 320 lb of dry waste from plastic media stripping, a reduction of 9,447 lb of hazardous waste per aircraft. These hazardous wastes from Hill AFB must be trucked to California for disposal in an approved hazardous waste disposal site, at a cost of \$200 per ton. In addition, solvent stripping operations require large volumes of wash water which must be chemically treated before discharge, compared to no water requirements for plastic media stripping. For F-4 aircraft, the wash water waste amounts to approximately 200,000 gallons per aircraft. The solvent stripping process also generates other environmental problems which are not generated in plastic media operations. Most significant are solvent vapor emissions, which pose a hazard to the workers and pollute the air. Paint dust is produced in plastic media blasting, so workers must be provided with filtered air. The dry paint residue from plastic media operations, although hazardous, is much less hazardous and poses fewer storage, handling, transportation, and disposal risks than the wet chemical hazardous sludge generated in solvent stripping operations.

The plastic media process requires significantly fewer manhours than solvent processes, while operator training and skill requirements are equal. Personnel can be readily trained to be proficient in using the plastic media equipment. Labor reductions amount to a 90 percent savings. For

of the carbon, and then steam is used to strip the adsorbed organics off the carbon. The solvent can then be recovered from the steam condensate.

3.4 Solvent Case Studies

3.4.1 Plastic Media Paint Stripping at Hill AFB

Industrial Process Description

The conventional technique most often used to remove protective and decorative paint coatings from aircraft and ground support equipment is chemical stripping. Hill AFB has historically used chemical stripping for F-4 aircraft in its aircraft maintenance program, which renovates approximately 215 aircraft per year. In the chemical stripping process a solvent, typically an acidic methylene chloride solution, is applied to the painted surface. The stripper's chemical action primarily destroys the bond between the paint and the substrate surface. After the stripper works on the paint (up to 4 hours may be needed) the paint will loosen so that it can be removed from the surface by squeegeeing, scraping, and washing. Depending on the type of paint top coat and primer, the number of layers, and the paint age, one or more applications of chemical stripper may be required; sometimes more than one type of stripper is required to complete the chemical stripping process. Followup handsanding and buffing are required to remove remaining paint. The paint/solvent mixture must be scraped and squeegeed from the aircraft surface and washed down with approximately 20,000 to 30,000 gallons of water for each application of stripper. The wastewater stream containing paint and solvent residues must be chemically treated before being discharged to the local municipal wastewater treatment plant. Paint and solvent scrapings are collected and disposed of at a hazardous waste disposal site. The on-base chemical treatment plant also generates large volumes of hazardous wastes which must be disposed of off-site at a licensed hazardous waste disposal site.

The chemical stripping technique is expensive and time consuming, releases noxious fumes into the work area, creates hazardous working conditions for the work force, and generates wastestreams which are difficult, costly, and environmentally hazardous to dispose of.

Process Modification Description

Plastic media paint stripping, one of the most promising alternative technologies to conventional solvent stripping (29, 30, 31), has been developed and successfully demonstrated for aircraft maintenance at Hill AFB, Ogden, Utah. In this process, old paint is removed with modified conventional sandblasting equipment using recoverable plastic

Table 3-7
SUPPLIERS OF SELF-CONTAINED DISTILLATION APPARATUS

Detrex Chemical Industries, Inc., Detroit, Michigan
Baron-Blakeslee, Melrose Park, Illinois
Corbane Industries, Inc., Louisville, Kentucky
Vapor Engineering, Inc., Pensacola, Florida
Phillips Manufacturing Co., Chicago, Illinois
Gardner Machinery, Charlotte, North Carolina
Finish Engineering, Erie, Pennsylvania
Recyclene Products, San Jose, California

An alternative to purchasing a still is to use an off-base recycler to distill solvents. This can be implemented either of two ways. The first is to contract with the off-base recycler to distill and return spent solvents. The second is to sell the solvents to the recycler. The best method to use depends on the availability of a local recycler, the type of solvent recycled, and the economics of on-base versus off-base recycling. Normally, it is preferable to use an on-base still because of cost, process control, and convenience advantages, as well as liability with respect to hazardous waste issues.

With some specialized solvents, the manufacturer will take back solvents for reprocessing at no charge or for a nominal fee paid by either the manufacturer or the user. This is usually an advantageous way of disposing of used solvents.

Centrifugation, Filtration, Ultrafiltration, and Reverse Osmosis

These technologies are appropriate for emulsion-type solvents used in machining processes but are not usually used for recycling cleaning solvents. Centrifugation and filtration are used to remove metal chips and other contaminants from machining processes, allowing the machine solvent to be reused. Most modern machining equipment can be supplied with built-in solvent recycling systems.

Ultrafiltration and reverse osmosis are used primarily to separate water from the emulsified oil streams. These processes are very waste stream specific and are not commonly used.

Activated Carbon

Activated carbon is usually used to capture airborne solvents. The airborne solvents are adsorbed onto the surface

cost about \$55,000. Generally the payback period for a still purchase is between 6 months and 2 years. The normal lifetime of a still is about 20 years.

Table 3-6
SOLVENT DATA SHEET

Solvent	Atmos. Boiling Pt (°F)	Azeo. Boiling Pt (°F)	Density (lb/gal)
<u>Aliphatic Hydrocarbon</u>			
Hexane	157	142.9	5.51
Heptane	209	174.8	5.70
Stoddard	308-316	204	6.47
<u>Aromatic Hydrocarbon</u>			
Benzene	176	157	7.32
Toluene	232	185	7.20
Xylene	261-318	202.1	7.17
<u>Chlorinated Hydrocarbon</u>			
Trichloroethylene	189	163.8	12.2
PERC	249	189.7	13.5
1,1,1-trichloroethane	166	149	11.0
Methylene Chloride	104	101.2	11.07
<u>Fluorocarbon</u>			
Freon TF	117.6	112	13.06
Freon 112	199	166	13.69
Acetone	133	133	6.59
MEK	175	164.1	6.71
MIBK	241	190.2	6.67

Source: DCI Corp., Indianapolis, Indiana.

Table 3-7 lists the major suppliers of self-contained solvent distillation apparatus.

The operating costs of distillation apparatus include labor, energy, cooling water, and maintenance parts. Normally, the largest component is labor. A moderately trained operator is needed to tend the apparatus about 10 percent of the time during operation.

In order for recycling to be effective, solvents should be segregated. If two or more solvents are mixed, an off-the-shelf still is often not able to separate them and a much more expensive, customized unit would be required. Solvent segregation is often the major obstacle to implementation of solvent recycling programs.

sustained without human discomfort. Unfortunately, the use of robotics as currently employed is better suited for private sector industries, which use mass production of vehicles and parts. Most military manufacturing and rework facilities paint and paint strip an extremely diverse number of parts and materials. These facilities are often not amenable to robotics since there is a wide range of variables (part sizes, shapes, materials, quantities, etc.) that can change during the course of a day.

3.3.3 Solvent Recovery and Reuse

There are many technologies available for the reuse and recovery of solvents. The most promising technology identified which can be applied to almost all DOD facilities is distillation. Solvent recovery using distillation can be implemented in four configurations: on-base recycling, off-base contract recycling, sale to off-base recyclers, and manufacturer take-back. Alternative technologies other than distillation that were identified as commercially available and that may have specific application for a particular process are centrifugation, filtration, ultrafiltration, reverse osmosis, and activated carbon. These alternative technologies are also described.

Distillation

This technology relies on heating a solvent sufficiently to vaporize it and then condensing the vapor (35). The condensed vapor is then reused. If the boiling point of the solvent is high (over 200°F), the distillation is usually done under a vacuum to lessen thermal decomposition of the solvent. Another technique used for high boiling point solvents is to inject steam into the solvent and form an azeotropic mixture that has a lower boiling point. The water and solvent condensate is then separated by gravity. Table 3-6 lists the solvents amenable to distillation along with important physical parameters. There is usually a 10:1 to 15:1 volume reduction of waste to be disposed of when recycle by distillation is used.

There are many commercially available distillation systems that can distill solvent quantities ranging from 0.5 to 100 gallons per hour. The smaller systems are self-contained, off-the-shelf units that can be installed in any sheltered area that has electrical power and cooling water available. The larger units are generally more complex and require the availability of steam. The capital cost is generally about \$5,000 plus \$1,000 per gallon per hour of capacity. For example, a 50-gallon-per-hour still would

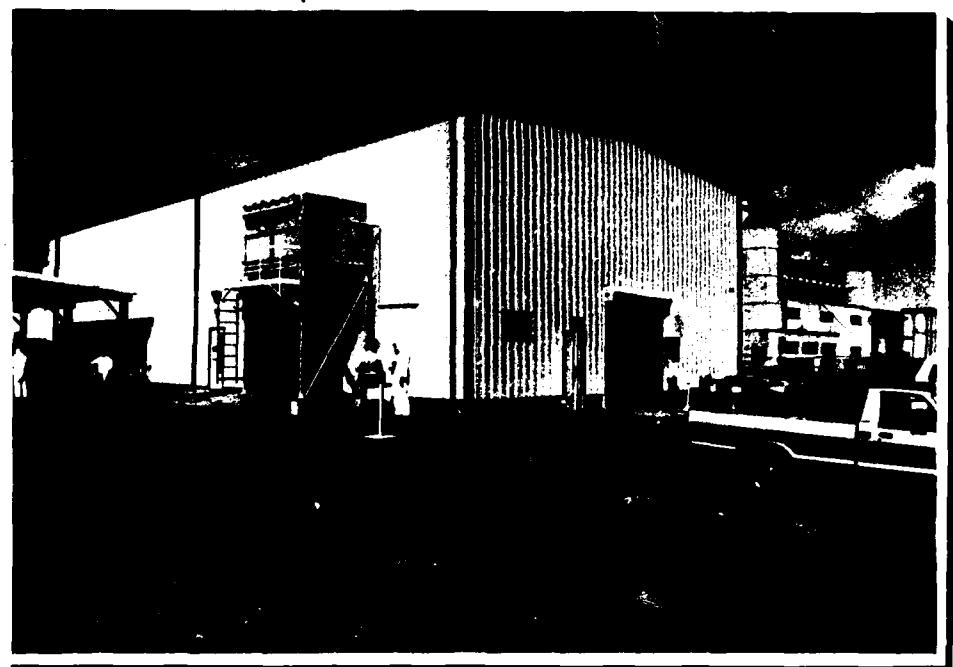


Figure 3-2. Building 223 Hill AFB PRAM plastic media paint stripping facility. On the left is one of two air ventilation dust collectors. The rollup door provides access to the mechanical equipment room. The main access door is located at the opposite end of the facility.



Figure 3-3. Equipment Room. Plastic media storage hoppers mounted above Paulli and Griffin blasting machines.

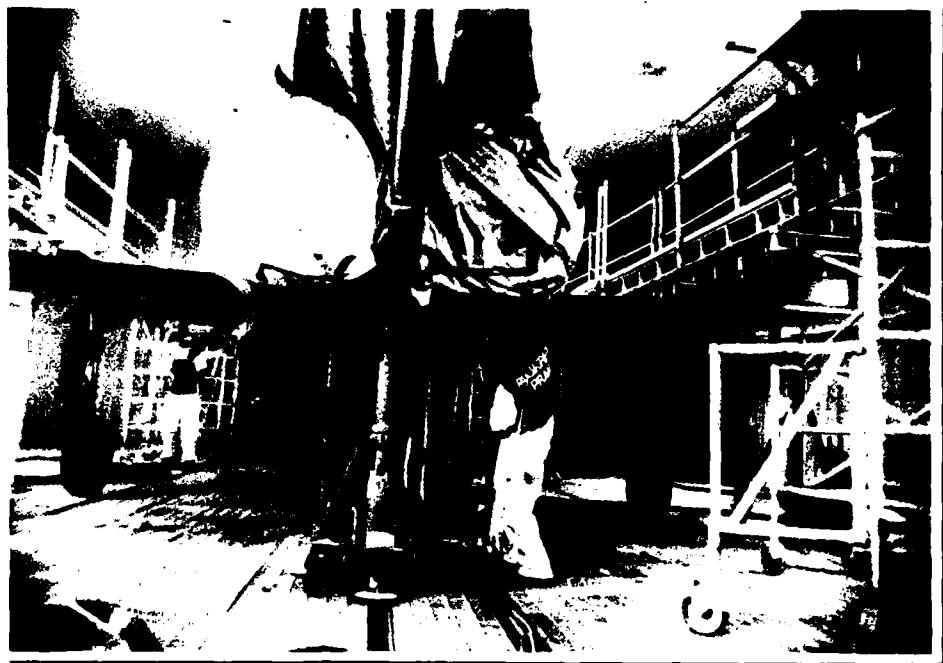


Figure 3-4. Plastic media stripping of F-4 aircraft (floor level view).

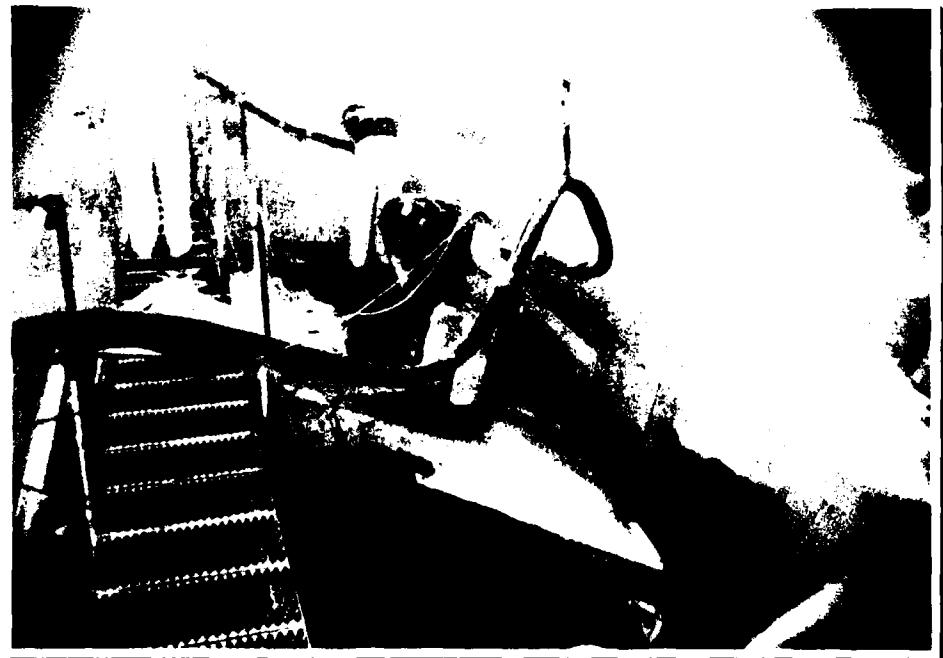


Figure 3-5. Plastic media stripping of F-4 aircraft (viewed from above).



Figure 3-6. Plastic media stripping peels the paint from the anodized aluminum surface without damage to the surface.

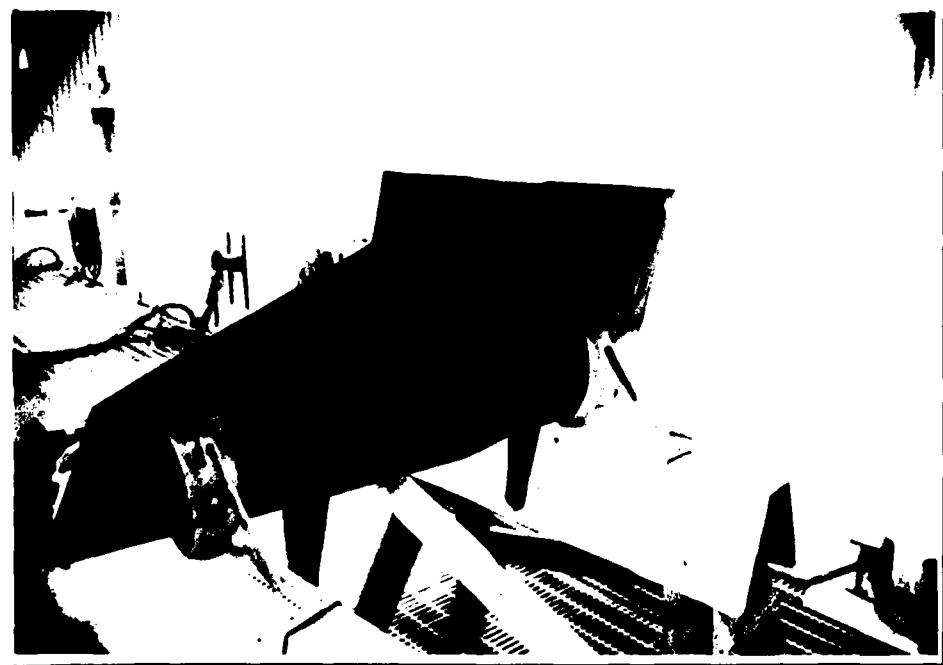


Figure 3-7. F-4 aircraft component mounted for stripping. Stripping right edge started.

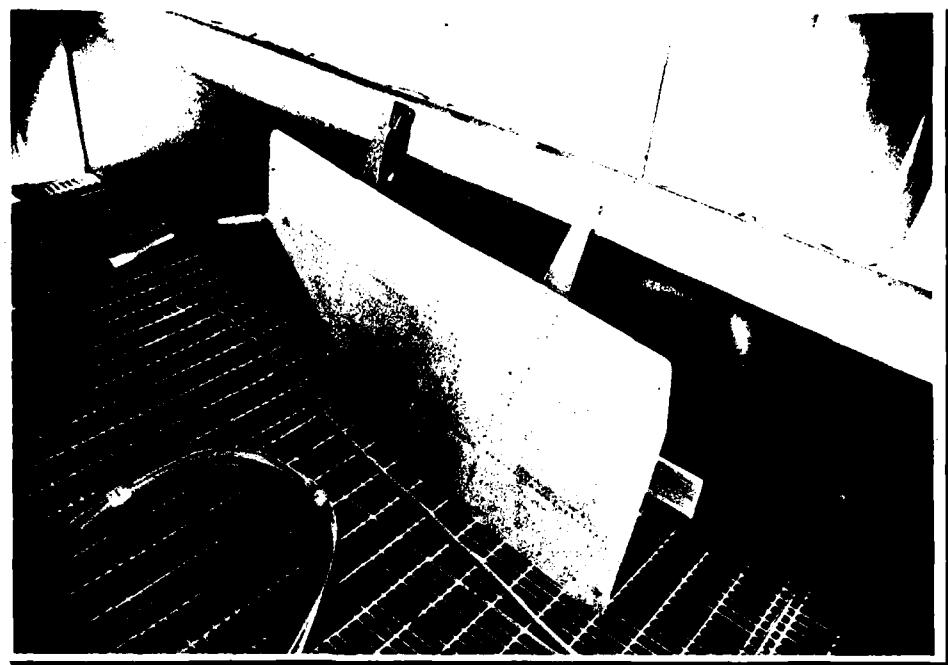


Figure 3-8. F-4 aircraft component stripping completed.

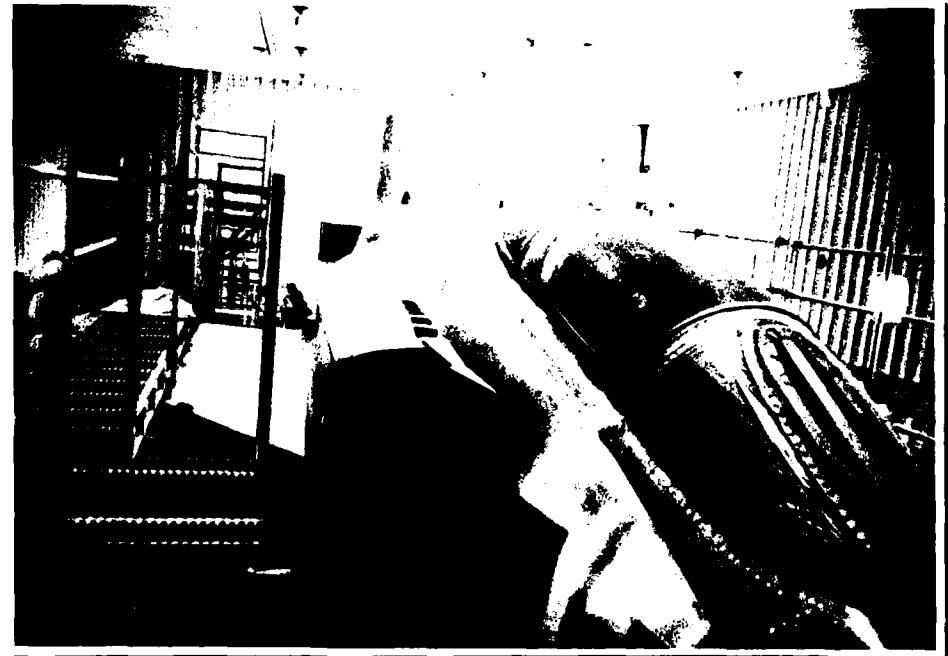


Figure 3-9. F-4 aircraft plastic media stripping completed. First full-scale test of system required five workers approximately 4 online hours to completely strip the aircraft.

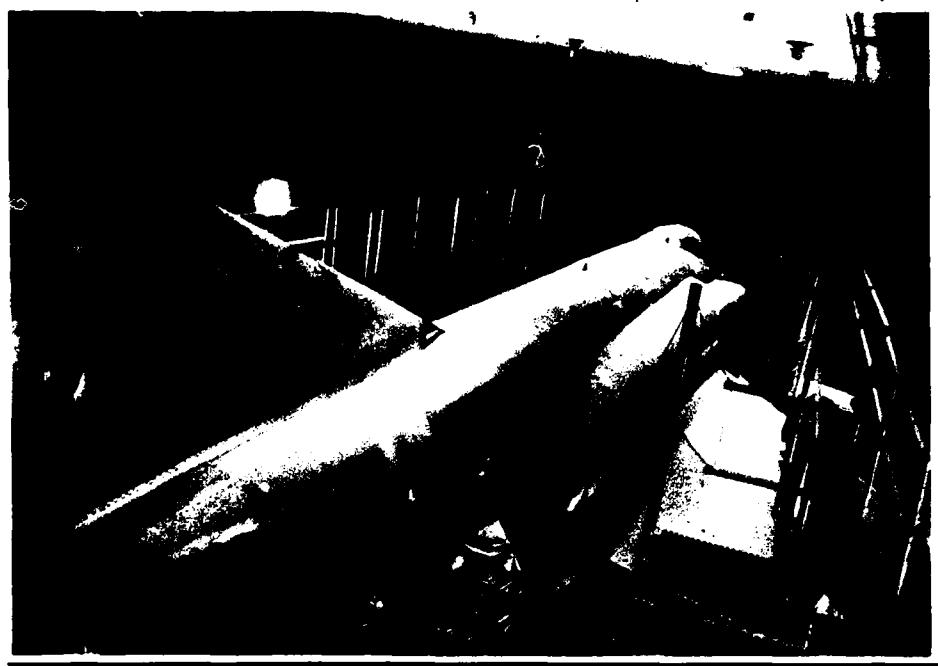


Figure 3-10. F-4 aircraft plastic media stripping completed. The anodized aluminum looks new. The aircraft paint included original primer coats.

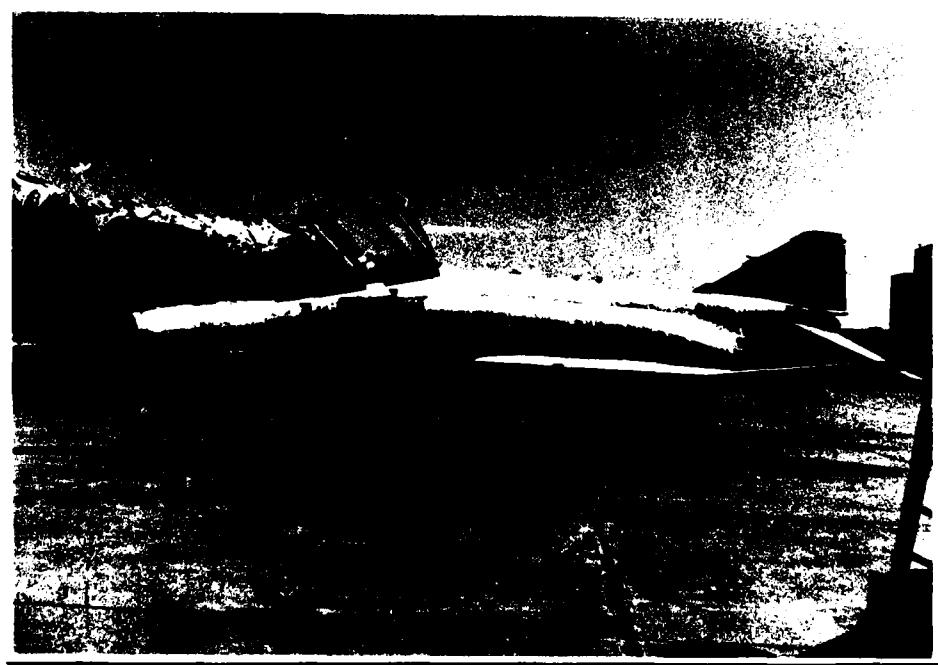


Figure 3-11. F-4 aircraft stripped by conventional solvent methods. Note the difference in surface appearance. The shiny aluminum indicates the anodized aluminum surface was damaged when paint was scraped off. Also note the brownish areas where the paint remains. This aircraft will be re-taped and stripped again.

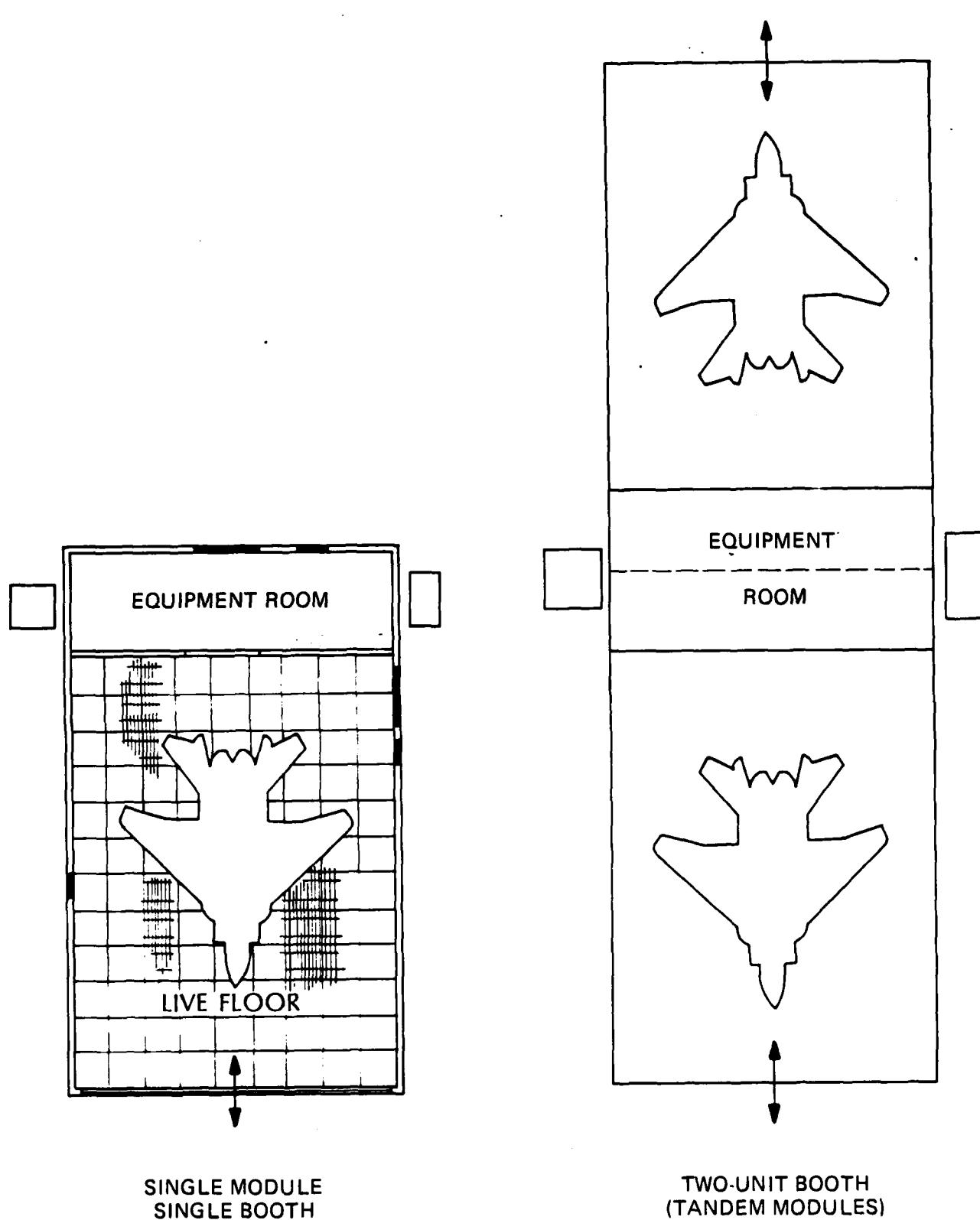


Figure 3-12. Layouts of single and two-unit plastic media blast booths.



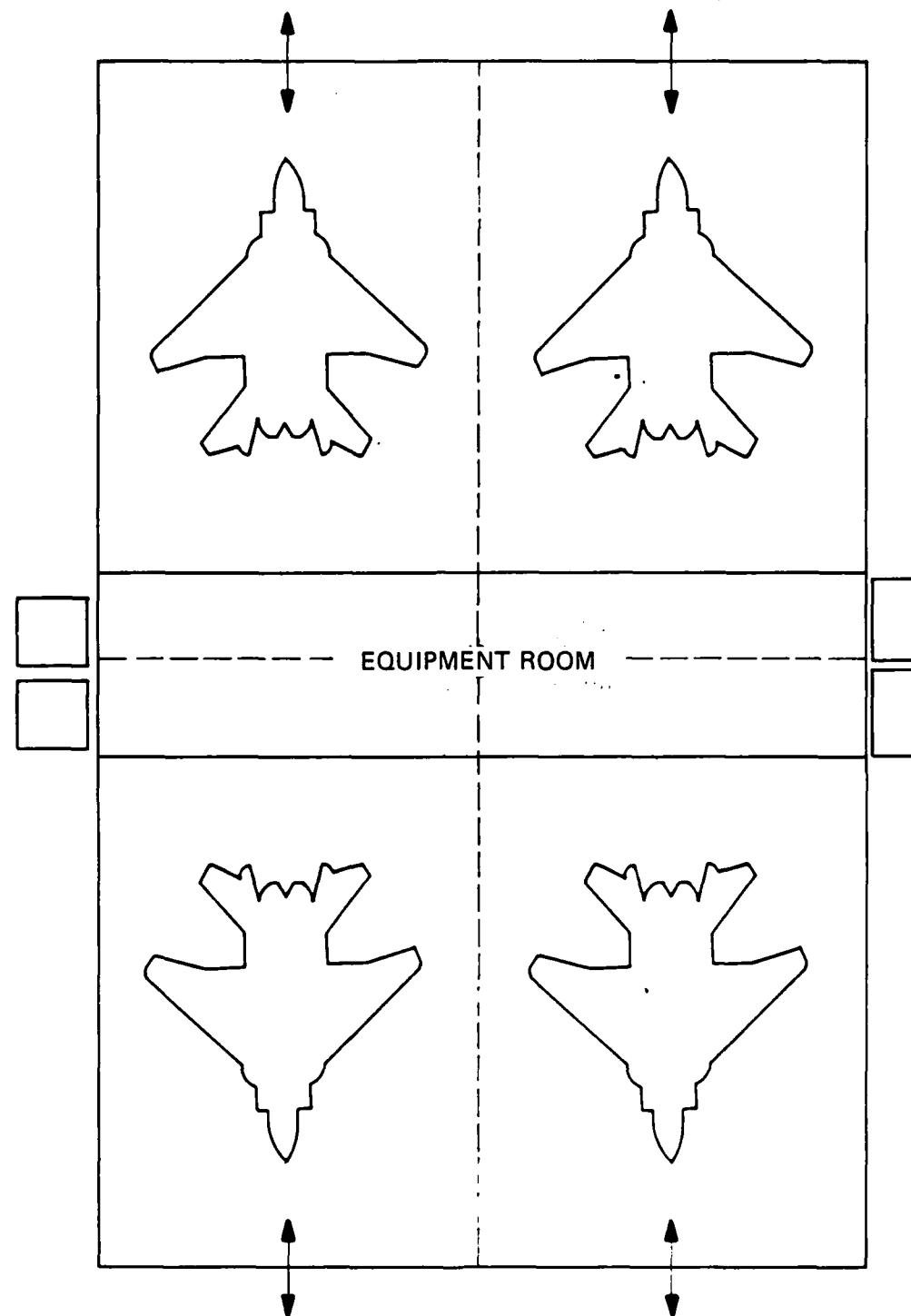


Figure 3-13. Layout of four-unit blast booth (double tandem modules)



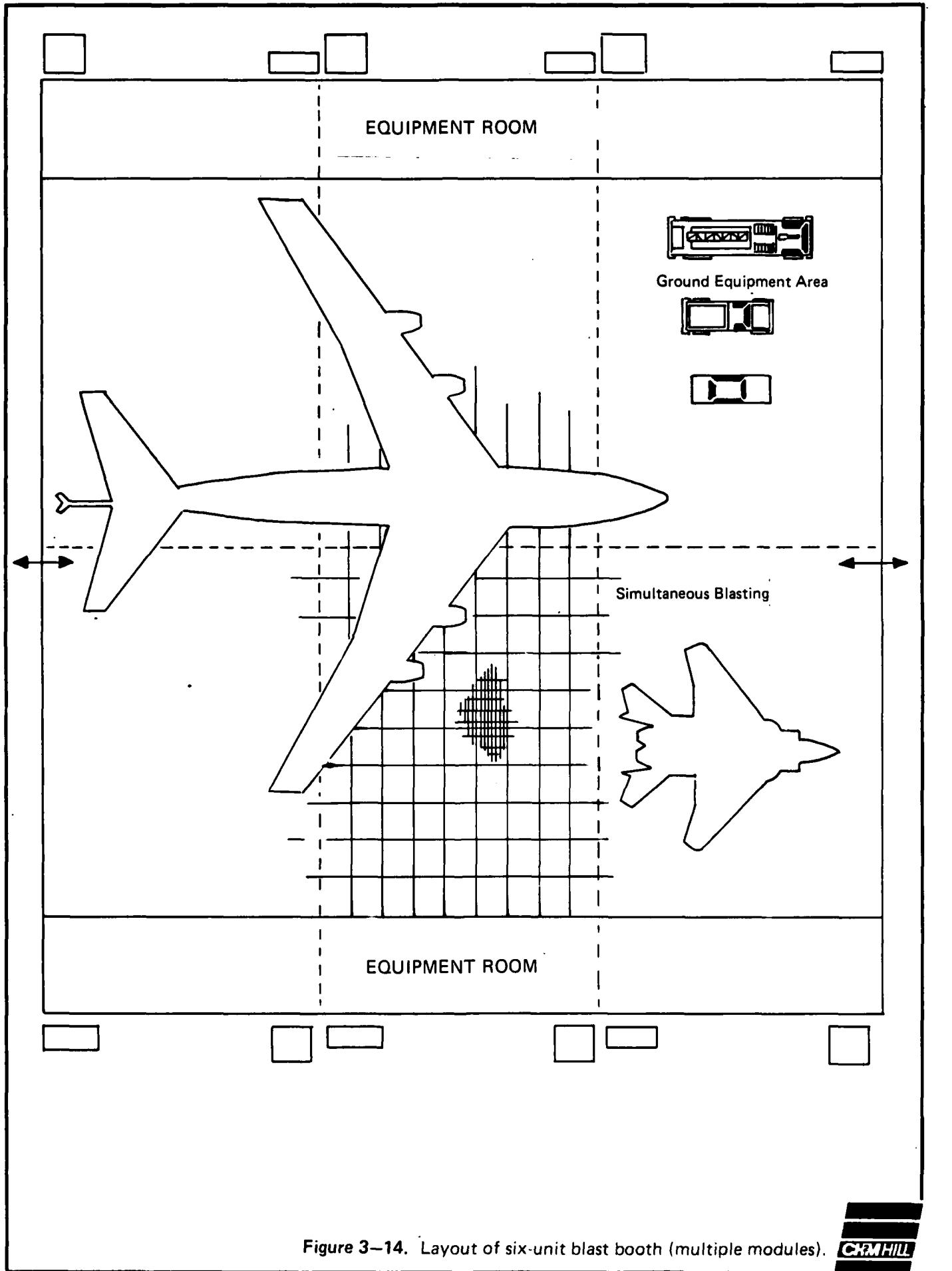


Figure 3-14. Layout of six-unit blast booth (multiple modules).

Some features of the blasting booth system are exclusive to Royce Mechanical Systems of Ogden, Utah and are proprietary.

The engineered module should include provisions for installation of the system in existing buildings, as well as installation at "new" sites. The system lends itself easily to both conditions with only minor considerations. The structural requirements of the building can be met with only a cover or shell and do not involve the support of any of the equipment. Therefore, local requirements can be easily met without affecting the blasting process.

Blast booths for other equipment such as vehicles, tanks, small boats, etc., would pose no problems as these all fit well with the single or tandem module facility.

A study should be conducted to determine standard aircraft hangar sizes, both military and civilian, before the module size can be established. An alternative would be to size the basic module, based on a range of aircraft sizes, i.e., a military fighter aircraft as the smallest, up to a C-5A as the largest. Anything larger would require special considerations but would still utilize the standard multiple module concept. The product of this study could be a standard turnkey specification that DOD facilities could use in procuring a module.

3.4.2 Dry Media Paint Stripping at Pensacola NARF

Industrial Process Description

The NARF at Pensacola, Florida, reconditions both H-53 helicopters and A-4 aircraft. Wet paint stripping is the most common technique used for removing paint from fixed-wing aircraft and parts at this site. Because of the fiberglass present in most helicopters, however, wet stripping cannot be used to remove paint since the solvents tend to dissolve the fiberglass resins. Consequently, sanding and grinding are used to remove helicopter paint. The method is laborious and requires skilled technicians.

Process Modification Description

In February of 1984, Hill Air Force Base invited Pensacola engineering personnel to their facility to brief the NARF on the new plastic stripping technique. Pensacola NARF was impressed with the demonstration and hence implemented the process at their own facility. Plastic media stripping is currently being performed in three enclosed glove boxes and one open room. Paint stripping using glass media is also performed in six glove boxes. Small hand-held parts are stripped in the glove boxes, whereas larger parts are stripped in the open room.

Approximately 75 percent of the paint coatings of small parts are presoftened prior to blasting with a cold carbon/paint removal solution consisting of 50 percent methylene chloride and other solvents (MIL-C-19853). Small components are placed in a basket and immersed in the solvent solution for 30 minutes to 2 hours. After drying, any remaining paint is stripped by the plastic media. Most of these parts could be completely stripped using only dry blasting; however, presoaking the parts substantially decreases the time the parts need to be blasted. Unlike small parts, large components are stripped of their coatings by the abrasive material without being presoaked.

All three types of plastic media manufactured by U.S. Plastics and Chemical Company are used at Pensacola NARF. The softest material, Polyextra, is used to remove paint from fiberglass surfaces and strip polysulfide sealant from various parts. Polyplus is applied on aluminum, manganese, and steel parts. The most abrasive material, Type 3, is blasted onto very difficult to remove coatings and on castings.

A program has been set up at Pensacola NARF in which every new part or material that comes into the NARF requiring stripping is tested with plastic media blasting. The ultimate goal is complete conversion to dry media stripping. However, some parts or materials may continue to require solvents for the initial stripping, followed by plastic media blasting for final paint removal.

Process Modification Experience

Pensacola has field tested stripping H-53 helicopters and tail sections of A-4 aircraft. To prevent any possible damage to active aircraft, the experiments were performed only on equipment that was retired from active service. Before fiberglass surfaces can be blasted, the thin skins must be adequately shored and braced to prevent damage to the aircraft. Plastic media blasting of the exterior of helicopters was found to be difficult. The main problem had been choosing the correct plastic beads and operating parameters for a given fiberglass resin. With hard epoxy resins, the plastic media blasting worked well. However, fiberglass that contains polyester resins is easily damaged with the plastic media. Unfortunately, the type of plastic media that should be used cannot be predetermined by visual inspection. Though extreme care must be taken using this method, Pensacola personnel have found that highly trained, skilled, and experienced technicians can strip paint from fiberglass surfaces without damaging helicopters.

Besides reducing hazardous waste generation, dry media blasting has produced additional benefits. For example, this method allows the NARF to strip surfaces, such as under-

belly struts of a helicopter (located underneath the floorboard), which could not be stripped by either wet solvent or grinding methods. Type 3 plastic media was successfully used to remove polysulfide sealant from the interior helicopter surface. In addition, the plastic media stripping does a complete job, whereas chemical stripping almost always leaves some residue to be hand sanded or ground off.

Plastic beads cannot be reused unless they are separated from dust and metallic paint chips. Pensacola NARF is not recovering plastic media for reuse. Rather, spent media from glove boxes is collected and packed in containers for disposal. The collection of waste material from the stripping of large parts is more difficult because the operation is performed in an open room. Waste material is allowed to fall to the floor, where it is then swept up and placed in containers for disposal. This cleanup process is both labor-intensive and inefficient.

In the past year, approximately 210 drums of contaminated glass and plastic beads had to be disposed of as a hazardous waste (due to cadmium and chromium) at an estimated cost of \$18,375 (\$87.50 per 250-lb drum). The cost of replacing the plastic media is \$425 per 250-lb drum. Thus, recovery of the plastic media could substantially reduce the costs of both hazardous waste disposal and material replacement.

Pensacola NARF acquired free of charge from Clemco, Inc., a NOVA blast cleaning recovery and reclamation system to test the feasibility of reusing plastic media on a trial basis. The NOVA system consisted of the following components: a blast machine, a high volume vacuum producer, an abrasive classification and screening system, and a dust collector. The NARF operated the recovery system on a steady basis for a 6-week test period (December 1984 - February 1985). Operating personnel were generally pleased with the performance of the equipment; however, they indicated that the experimental unit was not durable enough to withstand continuous operation. A specification is currently being written so that a Clemco NOVA unit or equal which meets industrial operating standards can be purchased for permanent use. Clemco's recovery system costs approximately \$20,000 to \$25,000. Based upon present media usage and a 75 percent recovery factor, the capital cost of the equipment would be recovered in only 3 or 4 months.

Future Direction

Pensacola NARF plans to replace the open blast room with two completely enclosed walk-in blast rooms which measure 20 feet long, 10 feet wide, and 12 feet high. These units, which cost approximately \$80,000 each, are expected to be in

operation by March 1986. These blast rooms are preferable to stripping paint in uncontrolled open rooms since air flow and dust levels can be measured and spent media can be efficiently recovered.

Four hangars are currently used for helicopter paint stripping. Pensacola's long-range goal is to convert two of these hangars to accommodate dry media stripping. Although capital funds are currently available for the hangar conversion, Pensacola is waiting for long-term production results from Hill Air Force Base and North Island NARF before investing in dry media paint stripping of thin skin helicopters. Personnel at Materials Engineering have expressed the opinion that stripping of H-53 helicopters is feasible; however, further laboratory research is required to determine the effects of blasting fiberglass surfaces on material fatigue, surface roughness, crack closure, and stress buildup. Materials Engineering also wants to further field-test prototype H-53 helicopters and A-4 aircraft at the NARF. Money, manpower, and equipment would have to be authorized in order to carry out the additional testing.

OSHA has expressed concern that dust generated from stripping operations poses a possible explosion hazard. An OSHA standard (29 CFR 1910.94) states that "organic abrasives which are combustible shall be used only in automatic systems..." This standard requires that combustible organic abrasives be used only in unmanned blast rooms. These regulations were written because of dusting problems associated with stripping paint using vegetable organics such as walnut shells, rice hulls, apricot pits, and corn cobs. These agricultural abrasives are much more prone to cause an explosive environment compared to the relatively low explosibility exhibited by plastic media (see Table 3-10). Although plastic media is technically an organic material (since it is a carbon compound), it is unclear if OSHA regulations should be applicable.

Table 3-10
EXPLOSIVE PROPERTIES OF DRY ORGANIC MEDIA

Property	Plastic Media			
	Polyextra	Polyplus	Type 3	Walnut Shell
Explosibility Index	5	0.2	<0.2	10
Ignition Index (°C)	440	530	>530	430
Minimum Explosive Conc. (oz./ft ³)	0.045	0.085	0.09	0.04

A conflicting American National Standards Institute standard (ANSI Z9.4a-1981) allows the use of organic material in manned grit-blast booths when combustible dust concentrations (less than 200 mesh) do not exceed one-fourth of the minimum dust explosive level. The Navy has proposed to the Department of Labor that dry media stripping using plastic beads be regulated by the ANSI standard instead of the OSHA standard. The Navy believes that the ANSI standard is more stringent than the OSHA standard, provided that a continuous airborne dust concentration monitoring system and an airflow measuring system are installed in each blast booth that uses organic material. According to the Navy, a monitoring system should be fitted with an alarm and an automatic shutdown device that is activated when the 200-mesh airborne dust concentration reaches 15 percent of the lower explosive limit of the organic material being used. An airflow device would shut the blast system down when the flow of air through the booth dropped below 100 ft/min for both downdraft and crossdraft ventilation.

The Department of Labor is currently reviewing the regulations and will determine which provisions apply. The Department has expressed the belief that plastic media paint stripping will be allowed provided that adequate measures are taken to minimize any possible hazard. The Navy will have to purchase instrumentation devices that can detect airborne dust concentrations and measure airflows in blast facilities. Pensacola personnel believe that it may be difficult to obtain monitoring devices which accurately measure these parameters. The NARF has sent samples of the plastic media to the Bureau of Mines to determine the lower explosive limit of the blasting material.

Until a final decision is reached, Pensacola reportedly intends to continue to strip paint with plastic media in enclosed glove boxes and open rooms.

3.4.3 Water-Based Painting Primer at Pensacola NARF

Industrial Process Description

Naval aircraft are typically coated with two layers of solvent-based paint. The primer is usually an epoxy polyamide compound conforming to Mil-P-23377. The topcoat is an aliphatic polyurethane compound meeting the requirements of Mil-C-83286. The primary function of the primer is to promote adhesion of the polyurethane topcoat and to protect the aluminum substrate from corrosion. In order to meet strict California VOC air emission standards, many military and military contractor facilities have recently switched to a water-reducible, amine-cured epoxy primer which contains low concentrations of VOC compliance solvents.

Process Modification Description

Although Pensacola NARF is not required to meet stringent VOC guideline limitations, they have recently investigated replacing conventional solvent-based primer with water-based material to improve product quality. Pensacola NARF has had considerable problems with solvent-based chromate primers (Mil-P-23377). Although Navy personnel at Pensacola have documented that some manufacturers' primers are more prone to difficulties than others, they have no control over which product is purchased since Navy Supply Center awards contracts based on low bids. Although manufacturers claim their products meet military specifications, Pensacola found that in actual field conditions, the solvent-based primers often fail to meet the specified requirements. In the past, approximately 20 percent of painted surfaces were rejected and consequently repainted because of product inferiority. Personnel at the Pensacola paint shop have expressed the opinion that the Government Services Administration (GSA) does not adequately test to determine whether a manufacturer's paints meet military specifications. Some solvent-based primers met military specifications and passed laboratory batch tests but performed poorly in actual field conditions. For example, a primer recently supplied from a manufacturer was found to peel and flake off from painted surfaces after being wetted.

Due to the poor quality frequently found in solvent-based primers, Pensacola NARF began experimenting with water-based chromate primers in August of 1984. The water-based primer chosen is manufactured by Deft Chemical Coatings Inc., and meets Navy Specification Mil-P-85582. This proprietary epoxy polyamide primer compound consists of barium chromate, 2-butoxyethanol, petroleum distillate solvents, nitroethane, and other unknown constituents. At application, the coating typically has a VOC less than 340 grams per liter, which is one-fourth that of conventional solvent-based primers, and consequently meets EPA's VOC limit of 420 grams per liter.

There are two types of Deft water-reducible coatings: standard (Type I) and low infrared reflective (Type II). Both of these coatings are supplied in two components--a pigmented resin solution containing corrosion inhibitors, and a clean unpigmented curing agent solution. The two components, which are packaged in a one-gallon kit, must be carefully mixed with 3 gallons of deionized or distilled water. The function of the water is solely to control the paint's viscosity during application. After the paint is mixed, the material is catalyzed and is ready for application. The catalyzed coating must be used immediately since it has a pot life of only 6 hours. After mixing, the primer can be sprayed onto aircraft parts using conventional spray paint guns. Once the water-based primer is applied to a surface,

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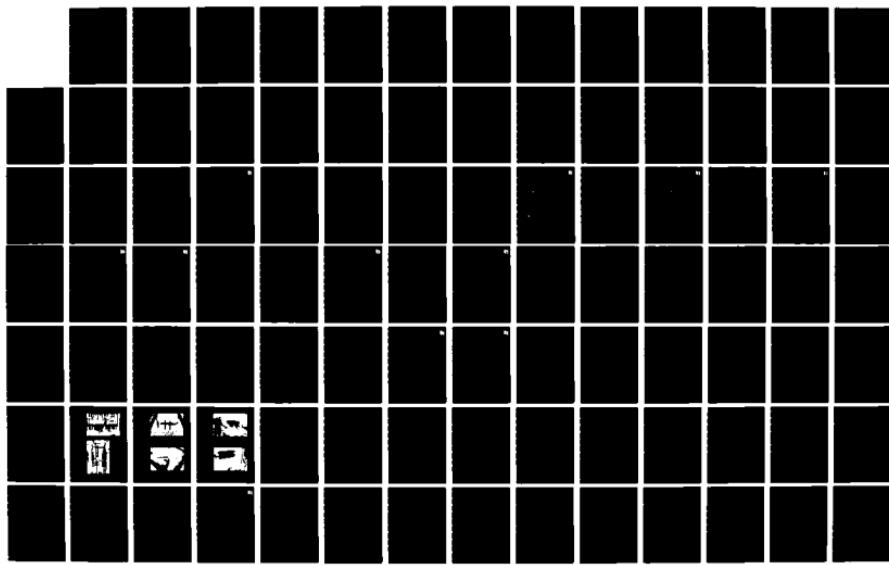
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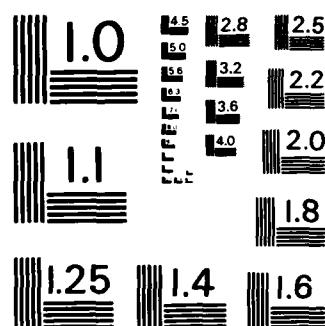
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MICROCOPY RESOLUTION TEST CHART
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the water evaporates, leaving the nonvolatile coating and some of the unevaporated solvent. At this stage of drying the film is similar to a high-solids coating without water. The solvent then evaporates, leaving the low molecular weight pigmented material. Reportedly, the final film is physically and chemically identical to an analogous film deposited by a solvent-based coating.

Process Modification Experience

Pensacola initially tried to spray paint whole H-53 helicopters with water-based primers and rely on solvent-based primers only for touchup work. They found that the primer frequently would not properly dry or adequately adhere to the porous surface due to the presence of ingrained oil. Pensacola personnel tried to first clean helicopter surfaces with freon and alcohol; however, the oils remained entrapped on the surfaces. Since approximately 50 percent of all painting performed at the NARF is the overspray of whole aircraft, water-based primers have the potential to only partially replace solvent-based primers.

Approximately 20 percent of spray painting currently being done at Pensacola NARF is being performed with a water-based primer. The decision to use water-based or solvent-based primer is made depending upon the specific application. A major application for the water-based primer is "low infrared" camouflaged surfaces. Parts painted with the water-based primer have had only a 2 percent rejection rate.

Although water-based paints take longer to dry than solvent-based paints, drying ovens are unnecessary due to the favorable Florida climate. During summer, a topcoat can be sprayed on a part one-half hour after application of the primer. During winter or high humidity periods, a part must dry for one to two hours before it can be repainted.

One advantage of water-based paints is that cleaning operations can be performed in most instances using only hot water and/or alcohol. Solvents are sometimes required for cleaning when paint is allowed to build up and harden, especially in confined areas such as spray gun orifices. Since solvents are not required to thin paint and are usually not required in cleanup operations, solvent usage and consequently solvent waste by-products can be substantially reduced. Unfortunately, solvent wastes from cleaning operations have not been reduced at the NARF since there has been no source of hot water in the paint building. Instead, paint personnel have used methyl ethyl ketone (MEK) for cleanup.

In essence, the general opinion of NARF experts is that water-based primers will work very well in selected applications, especially for parts which have been completely cleaned and stripped.

Painting personnel have pointed out several disadvantages of the new water-based primer, i.e., that it is more time-consuming and difficult to mix up, takes longer to dry, has a shorter pot life, and is more costly than conventional solvent-based paints. Also, deionized water must be obtained from the boiler shop, which further complicates the painting operation.

Waste paint solids, numbering approximately 250 drums/year, are sent to Chemical Waste Management's secure landfill located in Emelle, Alabama at a cost of \$23,000.

Future Direction

Pensacola is in the process of acquiring a water heater for the paint shop. The paint shop is also planning to switch to a less toxic, less volatile, and less expensive solvent for cleaning paint guns and lines, such as Mil-T-81772A, which is composed of MEK, butyl acetate, ethylene glycol, monoethyl acetate, toluene, and xylene. A deionized water supply will also be provided at the paint shop to decrease the difficulties in the makeup of primer solutions.

Materials Engineering, with the support of management, has been the driving force behind the introduction of water-based primers. It is believed that painting production personnel will become more receptive to the process modification once hot water and deionized water supplies are provided at the paint shop, and the use of cleaning solvents is expected to decrease. The problem with shortened pot life is anticipated to be only temporary. Pensacola NARF's goal is to totally replace the painting of parts with the Deft water-based primer. Oily surfaces of whole aircraft will continue to be painted with solvent-based primers.

3.4.4 Spray Painting at Lockheed-Georgia Company

Industrial Process Description

This site is a government-owned, contractor-operated facility in Marietta, Georgia, at which newly manufactured aircraft and aircraft parts are painted. Lockheed-Georgia Company operates the plant and is responsible for manufacturing C-130 and C-5 aircraft and modifying C-141 and C-5 aircraft.

Thirty-six paint spray booths are used in the painting facilities, four of which are dedicated for painting entire, finished aircraft. Twenty-one of the booths are water wall, and the remainder are dry wall. Conventional spray guns are used exclusively at the facility, applying primarily solvent-based, zinc chromate primer.

The primer consists of 20 to 22 percent solids and is a mixture of one part paint to two parts toluene. Lacquers are diluted one part paint to one part toluene paint thinner. Lockheed has investigated reducing solvent use, and consequently solvent wastewaters and paint sludge, by increasing the percent solids in the primer. However, it was difficult to control paint thickness since the dry film tended to build up quickly on intricate parts; therefore, this process modification was abandoned.

Waste products from the painting processes consist of about 50 drums/year of paint sludge and 170 drums/year of spent solvent, while over 125 tons/year of VOCs were emitted in 1983. Waste solvents consist primarily of 1,1,1-trichloroethylene, which is used in vapor degreasers, along with smaller quantities of toluene, which is used to thin paint, and MEK and xylene, which are used in cleanup operations. Wastewater from water wall spray booths is discharged to the industrial waste treatment plant, and the waste solvent is sold for \$0.15 per gallon to an outside contractor for recovery. Paint solids are removed from the water wells once a week and placed in 55-gallon drums. The solids are sent to Chemical Waste Management, Inc.'s secure landfill located in Emelle, Alabama at a cost of approximately \$60 per drum.

Process Modification Description and Experience

In 1980, a modern conveyor system was installed in the automated paint and process line used for painting small aircraft parts. Lockheed personnel spray paint aircraft parts as they move along the conveyor system. Parts can be plated, painted twice, and oven cured--if necessary, without being touched by human hands. After parts are spray painted, the paint racks are cleaned in a salt solution which removes any paint solids and impurities. This cleaning process produces small quantities of a hazardous paint sludge. Using the conveyor system for small aircraft parts has the following advantages:

1. Product quality is improved since impurities due to human contact are minimized.
2. A wide variety of part sizes and shapes can be handled by the conveyor system.
3. The speed at which the parts are painted is increased, since multiple handling is not required.

In conjunction with the new conveyor system, Lockheed has been retraining operators and inspectors on the proper paint thickness. There is a tendency for operators to overspray

parts with the primer, and overspraying an aircraft part results in excess weight for the aircraft. For example, if a C-5 aircraft were coated with 6 mil of primer instead of the specified 3 mil, the aircraft's weight would increase by several hundred pounds. The primary motivation of the training program is to reduce aircraft weight and paint material cost. If the training program is successful, the quantities of waste solvents and paint sludges should also be substantially reduced.

Lockheed has investigated several alternatives to solvent-based, human operated spray paint systems, as discussed below. In each case, the proposed modification was only temporarily implemented.

Robotics. To improve product quality and efficiency, and reduce paint overspray, robotics were employed by Lockheed. The robot had the capability to paint an 8-foot by 6-foot rectangular area and could be used for both normal spray painting and electrostatic painting. Usage was discontinued, however, because of difficulty in spraying the irregularly shaped aircraft parts. This robotic unit may be moved to the skin paint line where the parts are larger and more uniform in shape.

Water-Based Primer. To reduce hazardous waste generation, Lockheed tested water-based primers to determine if they could replace solvent-based primers. The company was hesitant to make the change, believing that the useful life of water-based primers was shorter than that of solvent-based primers. While water-based primer does meet the military specifications requirement for a useful life of 500 hours, solvent-based primers can last up to 2,500 hours. Therefore, Lockheed reportedly intends not to make the change on a permanent basis unless the performance of the solvent-based primer can be equalled or exceeded, regardless of the quantities of hazardous waste produced. Lockheed personnel expressed the belief that solvent-based paints are lighter for the same thickness as water-based paints, less expensive, easier to apply, easier to remove for inspection, and more durable. Solvent based primers also dry much more rapidly than water-based primers. If Lockheed were to make the change, ovens would have to be installed to hasten the drying of painted aircraft parts.

In 1960, the skin paint line was installed to coat aircraft parts to protect them from scratching and corroding while the aircraft are being assembled. From 1960 to 1983, Fabrifilm, a solvent-based coating, was used to provide protection to the aircraft surfaces. Water-based coatings were tested in 1983, and are presently being used along with Fabrifilm coatings to provide protection. Water-based coatings are used only to provide in-house protection of aircraft surfaces during assembly and are removed prior to final aircraft painting.

Powder Painting. In order for powder coatings to be activated, the coating and substrate have to be heated to 350°F. Since the majority of aircraft parts at the site contain aluminum, which cannot be heated above 250°F, the study of powder painting was discontinued.

3.4.5 Electrostatic Dry Powder Painting At Hughes Missile Division

Developmental Program Description

At Air Force Plant No. 44, operated by the Missile Systems group of Hughes Aircraft Company in Tucson, Arizona, electrostatic dry powder painting is being used in a developmental program to paint missile parts. Electrostatic dry powder painting was selected over other conventional paint systems because of enhanced corrosion protection, better coverage, and reduction in solvent emissions for the initial application in painting the inside fuselage section of the Phoenix Missile. The developmental program results have been very successful. In addition to satisfactorily achieving the initial goals, the dry powder painting system developmental program has shown that this system provides additional significant benefits, including reduced hazardous waste, eliminating wastewater, fewer man-hours, less paint use, and lower overall cost per square foot of painted surface. The developmental program is continuing and in-house implementation is being evaluated.

Industrial Process Description

Most painted parts used in the fabrication of missiles are painted using the solvent-based wet spray technique. Paint is applied in spray booths, where overspray is collected in a conventional air ventilation system equipped with a recirculating water curtain scrubber which removes the overspray from the exhaust air. The scrubber wastewater containing the overspray is treated in the central facility wastewater treatment system, where the overspray ultimately becomes part of the treatment plant wet sludge, which is a hazardous waste. Waste solvents and paint/solvent wastes are also generated from mixing operations, cleaning operations, empty containers, and waste materials which are hazardous wastes and require hazardous waste disposal.

Alternative painting technologies were evaluated for painting the interior surface of the fuselage section of the Phoenix missile, an area not previously painted. Coating this area to enhance corrosion protection from the salt environment present in aircraft carriers and from SO₂ present in jet engine exhaust was desirable. The area is small, approximately 9 square feet, and unit production is nominal, approximately 50 per month. The requirements provided the opportunity to test alternative painting technologies on a developmental scale.

Process Modification Description

The paint system is a polyester and epoxy powder coating that is electrostatically applied and fusion bonded. Paint materials are Type I--thermosetting polyester epoxy powder base coating or Type II--thermosetting epoxy powder base coating; and Class I--nonzinc-filled polyester or epoxy powder base coating or Class 2--zinc-filled polyester or epoxy base coating. The paint system standards include Mil-C-5541 (Chemical Films and Chemical Film Materials for Aluminum and Aluminum Alloys) and Mil-C-5624 (Turbine, Fuel, Aviation, Grades JP-4 and JP-5). Material vendors are Polymer Corp., Reading, PA for Type II, Classes 1 and 2, and Ferro Corp., Cleveland, OH for Type I, Class 1.

In the developmental program a local vendor is being used to apply the paint. He is using Solids Spray 90XC manual powder coating equipment manufactured by Volstatic, Inc. The equipment provides consistent coating thickness, even on complex surfaces. This portable unit has a 45-pound powder storage drum. The powder is fluidized and delivered through a venturi gun applicator. Total air consumption is minimal, at 6 scfm, with good dry powder delivery rates up to one lb/min. Constant or variable voltage control provides the electrostatic charge to the powdered particles, which electrostatically bind to the surface being coated. The coated part is fusion-cured in conventional ovens. For this specific application, curing temperatures are between 325 and 375°F as compared to conventional solvent-based paint, which would require 180°F.

Comparison of Electrostatic Painting Versus Conventional Painting

Technical and economic advantages of the electrostatic powder painting process compared to conventional solvent-based painting result in (1) a one-third reduction in curing time, saving both energy and labor and (2) a reduction in the number of coats per unit from two to one, saving material cost and labor. The material and labor cost savings are estimated to be \$1.05 per square foot of coated surface. The cost for the electrostatic painting equipment is minimal; the unit used in the development program costs approximately \$3,500.

Implementation of the electrostatic powder paint system requires minimal facility changes. At the Hughes Tucson plant the portable powder coating equipment is used in existing conventional wet spray booths. Estimated personnel training time is only 2 weeks. If the use of dry powder painting is expanded, the wet spray booth water scrubber system could be replaced with a dry bag powder overspray collector, which

would eliminate wastewater overspray discharge. The collected dry residue would still require hazardous waste disposal, but the volume of wastes would probably be less than the wet sludge generated in conventional spray painting because there would be less paint overspray.

Hazardous waste production is minimized using the dry powder painting technology. Since the coating is dry, the empty material containers are free of residual material and can be disposed of as normal refuse. Again, because the material is dry, solvent use for clean-up is much reduced and solvent use for mixing paint formulas is eliminated. The number of paint types needed may also be reduced for multiple applications; thus wastes from partially used containers and shelf-life-limited stored material will be reduced. Using a dry bag overspray collector will minimize the volume of hazardous waste generated by overspray and eliminate the wastewater that would need treatment.

Continued Program Development

Hughes Aircraft Company, Air Force Plant No. 44, is continuing the electrostatic dry powder painting development program to assess the system's technological and economic criteria, constraints, and potential uses. The Navy has approved dry powder painting on interior surfaces and is considering exterior surface approval and painting specifications. The Air Force has not yet approved the dry painting process.

3.4.6 Solvent Recycle Program At Robins AFB

Industrial Process Description

Warner Robins Air Force Base, located in Macon, Georgia, is a government-owned, government-operated (GOGO) facility that employs over 25,000 people. The base, which was constructed in 1942, is an Air Force Logistics Command installation that has the mission of refurbishing and maintaining airlift aircraft, fighter aircraft, bomber aircraft, utility aircraft, remote control aircraft, helicopters, and missiles. The base predominantly repairs C-130 and C-141 transport planes and F-15 fighter jets.

The Directorate of Maintenance, which employs approximately 6,000 workers, has the responsibility to purchase, transport, and dispose of hazardous chemicals. In fiscal year (FY) 1983, the Directorate of Maintenance used 3,700 drums (55 gallons each) of chemicals plus a variety of smaller packaged chemicals for repair operations. Approximately 45 percent of the chemicals used were either consumed in the process, evaporated into the atmosphere, or discharged with wastewater for treatment. The remaining waste material was collected in 55-gallon drums for disposal or recovery.

Prior to the passage of RCRA in 1980, drums of hazardous waste with no resale value were disposed of in a landfill located on the base. The leakage of hazardous chemicals from some of the drums contaminated the surrounding soil. Semiannually, used solvents and other organic fluids were sold for recycle and reuse. Since the passage of RCRA, the Defense Property Disposal Office (DPDO) has had sole responsibility for disposal and sale of hazardous wastes. Stringent RCRA regulations have discouraged buyers from purchasing used solvents and other organic fluids for recycling. Therefore, DPDO pays contractors from \$60 to \$100 per drum to dispose of hazardous waste in federally approved hazardous waste landfills. In order to minimize the volume of chemicals requiring disposal, a chemical reclamation program was initiated at Robins in March of 1981.

Process Modification Description

In 1982 Robins AFB purchased a batch, atmospheric pressure still manufactured by Finish Engineering Corporation for \$48,000. The still is used to reclaim trichloroethane, Freon-113, and isopropanol. In 1983, the Directorate of Maintenance's Chemical Control Group distilled 227 drums of chemicals for a savings of \$81,000. O. H. Carstarphen, Solvent Reclamation Engineer, estimated that in FY 1984 the recycling of the three chemicals saved the base \$118,000 in virgin material and hazardous waste disposal costs. It cost only \$13 per drum to reclaim the used chemicals, whereas disposal of the chemicals and repurchase of new materials would have cost from \$250 to \$500 per drum.

Process Modification Experience

The organic fluid recovery system consists of a single-stage batch still, a solvent/water separator, and an electrically powered steam generator. The still can operate up to a temperature of 300°F in the pot and can reclaim organic fluids at a rate of up to 55 gallons per hour. Freon and isopropanol were processed at a rate of approximately 50 gallons per hour, and trichloroethane was processed at a rate of 35 to 40 gallons per hour. Recovery efficiency for isopropanol and Freon-113 is approximately 95 percent. The recovery efficiency for trichloroethane is only 70 percent since the used material contains nonvolatile waxes, dirt, and greases that are removed from metal parts during degreasing operations.

The Finish Engineering still has been easy and inexpensive to operate and maintain. Some problems were initially encountered with a feed pump when recycling Freon, but these have been solved.

Freon-113 is predominantly used in the gyro shop and in the aircraft sealant operation. The reclaimed Freon does not

meet Type I military specifications; however, it does meet Type II military specifications and is consequently used for initial cleaning. New, virgin material is used for final assembly cleaning operations that require Type I Freon.

Presently, 584 drums of degreasing solvents are used annually by the Directorate of Maintenance. Trichloroethane is recycled since it is the predominant solvent used at Robins. Approximately 175 drums per year of trichloroethane are currently being reclaimed for reuse in vapor degreasing tanks located in the plating shop. Laboratory tests of the reclaimed trichloroethane have indicated that the material meets military specifications. The Directorate of Maintenance estimated that since July 1982 recovery of waste trichloroethane has amounted to a savings of approximately \$79,000.

Isopropanol is used in the Airborne Electronic Division for the cleaning of electronic parts. The alcohol was previously discarded when the solution became contaminated with oils and dirt. Isopropanol is currently being reclaimed by the organic fluid recovery system, resulting in a savings of \$16,200 in FY 1983 and \$18,500 in FY 1984. A 5-micron filter was installed in the discharge line for removal of fine metal particles that were carried over with the alcohol vapors. The reclaimed alcohol had a purity of 99.8 percent.

Future Direction

Recycling at Robins has been successful because personnel prevent the mixing of wastes and keep excessive water and other impurities out of the waste slop cans and drums. Segregation of the waste liquids is necessary in order to maintain the usefulness of the recovered organic fluids. For example, two common paint thinners, MEK and toluene, could easily be mixed together in the waste slop drums in the painting shop. However, if this were to occur, the mixture could not be effectively separated by single-stage batch distillation because the boiling points of the two thinners are similar.

Management's commitment to the organic fluid recovery operation has been very strong, as demonstrated by the facilities and manpower dedicated to the operation of the system. Waste chemicals at Robins AFB are collected at 30 different areas by the Chemical Control Group. These collection areas have controlled access, are covered, and are on diked concrete pads. The areas are used for both the dispensing of fresh solvents from drums and the collection of waste solvents in separate, labeled drums. Site managers are responsible for the segregation of wastes at the different sources. The Chemical Control Group, which consists of ten people, is responsible for performing the following tasks:

sampling all drums; redistilling Freon, trichloroethane, and isopropanol wastes; and transporting the reclaimed materials back to their source. In addition, analytical chemists are required to perform two sets of analyses for each drum of waste. First, as each drum is received, the contents must be analyzed to confirm the labeling. After each distillation run the recovered solvent is also analyzed to ensure that it meets appropriate specifications.

Hazardous wastes that cannot be reclaimed are transported to the DPDO storage facility located on the base for sale, donation, or ultimate disposal.

One additional management tool implemented at Robins AFB to educate base personnel about hazardous wastes has helped the reclamation program succeed. The Directorate of Maintenance developed a course titled "Storage, Handling, and Disposal of Industrial Chemicals," which is attended by all personnel who store, handle, use, and/or dispose of industrial chemicals. The scope of this training includes industrial materials terminology, personnel protective equipment, hazard identification systems, emergency procedures, and industrial waste collection and disposal.

Robins AFB recently purchased a second still from Finish Engineering for \$97,000 to supplement their existing unit. By using a vacuum, this new system will have the capability of distilling organic fluids that have atmospheric boiling points up to 500°F while maintaining a 300°F limit in the still's pot. This new still is to be used to recover materials, such as PD-680 dry cleaning solvent and silicone damping fluid, that cannot be reclaimed with the existing still. The new still will also be used to reclaim materials, such as paint thinners (e.g., MEK and toluene) and Coolanol 25R fluid, that were not being recovered because of inadequate capacity. According to maintenance personnel, the total potential savings in material costs and disposal costs for the new still is expected to be \$315,000 per year.

In addition, the Directorate of Maintenance obtained a vacuum still from Tyndall AFB that was out of service (see 3.4.8).

3.4.7 Paint Solvent Recycling at Norfolk NSY

Industrial Process Description

At Norfolk NSY approximately 15 gallons per day of numerous waste solvents including mineral spirits, ketones, and epoxy thinners containing paint pigments are generated in the paint shop during cleaning operations. Historically, the waste mineral spirits and other waste organic fluids have been disposed of by DPDO at a reported cost of \$7.80 per gallon.

Process Modification Description

A nonfractionating, batch still, Model LS-15V, manufactured by Finish Engineering, Erie, Pennsylvania, is used at Norfolk NSY. This model is designed to recover 15 gallons of solvent per shift of operation (i.e., one full charge of the still pot). The system employs an electrically heated pot with a residue collection pan, a water-cooled shell and tube condenser, a reclaimed solvent collection tank, and an electric vacuum pump. The system is designed to recover organic fluids with boiling points in the range of 100°F to 320°F without using the vacuum system. The vacuum system, which produces a vacuum of 25 inches of mercury during operation, is designed to recover organic fluids with atmospheric pressure boiling points up to 500°F.

The system produces a solid residue in the still pot's residue collection pan. The collection pan is then removed, and the residue is emptied into a container for disposal. The cost of this system (uninstalled) was approximately \$9,000. The same system without the vacuum system option cost \$5,000.

Process Modification Experience

The day of the site visit was the first day of system operation with the vacuum accessory. Preparation for startup took only 15 minutes; the system was started with only one button and then ran unattended. On the day of startup, mineral spirits were distilled under vacuum. A teflon gasket on the still pot became deformed, apparently as a result of the vacuum. The paint shop foreman removed the gasket and was able to maintain 22 inches of vacuum in the system. Dry paint solids remained in the collection pan after the cycle was completed. These solids were easily removed for disposal. The system recovered approximately 13 gallons of solvent from a 15-gallon charge of waste solvent for an 85 percent recovery.

The system had been used successfully without the vacuum system to recover organic fluids with boiling points below 320°F. Norfolk reported recovering more than 50 percent of the waste solvent at a cost of about \$0.05 per gallon operating at atmospheric pressure.

This solvent recovery operation has experienced continued success since the site visit. The system as installed is expected to continue recovering methyl isobutyl ketone, MEK, epoxy thinners, and mineral spirits, provided solvent segregation practices are maintained.

The indirect heating employed by this system eliminates the wastewater generated by direct steam heated stills and the resultant problems of treatment and disposal.

A certain amount of organic vapors is pulled through the vacuum pump and vented to the atmosphere. The amount, flammability, and toxicity of organics discharged should be considered. Also, the long-term effect of these vapors on the vacuum pump should be evaluated.

Future Direction

This solvent recovery operation had three key elements which combined to make it a success: personal dedication of a production representative, technical innovation and ease of operation, and physical location where the waste was generated. Jake Coulter, the Paint Shop Foreman, has been the champion of this solvent recovery operation. He has wanted it to work, and it appears to have been a great success.

3.4.8 Stoddard Solvent Recycling At Tyndall AFB

Industrial Process Description

At Tyndall Air Force Base, Panama City, Florida, solvents have been used in the general maintenance of jet aircraft and motor vehicles. In 1981 the Air Force Engineering and Services Laboratory initiated a research project at Tyndall to determine if solvents could be economically recycled on the base. Stoddard solvent was selected as the organic liquid to be recovered in this project. Stoddard solvent (Military Specification PD-680) is an aliphatic petroleum distillate and is used at Tyndall primarily for metal cleaning and degreasing. In 1981 it was estimated that approximately 13,000 gallons of Stoddard solvent were being used per year at a total of 19 different shops, making it the most widely used solvent at Tyndall.

Process Modification Description

The solvent recovery system employed a vacuum still system manufactured by Gardner Machinery, Charlotte, North Carolina. This system had a rated overhead capacity of 200 to 225 gallons of solvent per hour and was designed to process Stoddard solvent, naphtha, mineral spirits, and petroleum spirits.

The system at Tyndall was heated indirectly with steam, which was generated in an electrically heated boiler. This system could generate saturated steam at a pressure of up to 100 psig.

Table 4-1
HAZARDOUS WASTE FROM NONSPECIFIC SOURCES

EPA Hazardous Waste Number	Hazardous Waste Description	Hazard Code Designation
F006	Waste treatment sludges from electroplating operations except from the following processes: (1) sulfuric acid anodizing of aluminum; (2) tin plating on carbon steel; (3) zinc plating (segregated basis) on carbon steel; (4) aluminum or zinc-aluminum plating on carbon steel; (5) cleaning/stripping associated with tin, zinc, and aluminum plating on carbon steel; and (6) chemical etching and milling of aluminum.	Toxic
F007	Spent cyanide plating bath solutions from electroplating operations where cyanides are used in the process (except for precious metals electroplating spent cyanide plating bath solutions).	Reactive, Toxic
F008	Sludges from the bottom of plating baths in electroplating operations where cyanides are used in the process (except for precious metals electroplating bath sludges).	Reactive, Toxic
F009	Spent stripping and cleaning bath solutions from electroplating operations where cyanides are used in the process (except for precious metals electroplating spent stripping and cleaning bath solutions).	Reactive, Toxic

If a facility produces over a 1,000 kg per month of hazardous wastes, it must comply with all RCRA regulations. In the October 1984 reauthorization of RCRA, Congress

control than zinc plating; and (4) cadmium is somewhat superior to zinc in corrosion protection in marine (salt) environments. Parts that are to be cadmium plated typically are cleaned of grease, oil, dust, and rust by undergoing solvent vapor degreasing, alkaline cleaning, and acid pickling. Once a part is cleaned, it is cadmium plated and then heated to remove hydrogen (to prevent hydrogen embrittlement).

4.2 Magnitude of the Problem

4.2.1 Plating Wastes--Environmental Regulations

Hazardous Wastes

The Resource Conservation and Recovery Act (RCRA) and the associated federal regulations (40 CFR 261) define hazardous wastes which are produced from electroplating operations. Metal plating baths, cleaning solutions, and sludges are automatically defined as hazardous wastes if they are listed in one of EPA's generic categories for nonspecific sources (40 CFR 261.31). Table 4-1 summarizes the generic categories of hazardous waste applicable to the electroplating industry. Metal plating waste can also be classified as hazardous if it exhibits any of the characteristics identified below:

Ignitability - Liquid with a flash point below 140°F, nonliquid which burns vigorously and persistently when lighted, ignitable compressed gas, or an oxidizer.

Corrosivity - Liquid with pH less than or equal to 2 or greater than or equal to 12.5, or liquid which corrodes steel (SAE 1020) at a rate greater than 0.25 inch per year.

Reactivity - Substance which is normally unstable and readily undergoes violent change without detonating, reacts violently with water, forms explosive mixtures with water, generates toxic gases, vapors, or fumes when mixed with water, or is capable of detonation.

Toxicity - Waste that fails the extraction procedure (EP) test (i.e., a measurement of the leaching of heavy metals and pesticides from sludges).

A more detailed description of the four characteristics can be found in 40 CFR 261.2.

4. METAL PLATING RELATED MODIFICATIONS

4.1 Description of Metal Plating

Plating is the deposition of a thin layer of metal on the surface of a basis metal for the purposes of changing the properties of the basis metal. These modifications may be to improve the appearance (decorative plating), to increase resistance to corrosion, or improve hardness, durability, solderability, or frictional characteristics of the basis metal. Plating is a subset of metal finishing, which includes painting and operations that modify the properties of the basis metal (e.g., anodizing of aluminum).

The principal metals plated at military facilities are chromium, cadmium, nickel, and zinc.

Chromium is used principally in the remanufacturing of worn parts whose replacement with new parts would be infeasible because of their unique design. Remanufacturing consists of machining the worn part or stripping a portion of the old plate, overplating with a thick layer of chromium (hard chrome plating), and machining back to original specifications. The remanufactured parts are often of better quality than the original parts due to the thick chromium plate. Parts are typically plated for longer than 24 hours, to achieve the required thickness of chromium.

Nickel, cadmium, and zinc are plated to provide a corrosion protection finish to parts. These coatings are significantly thinner than hard chrome plates, and are applied in minutes, rather than the hours or days required for hard chrome plating. Nickel is applied to new parts for corrosion and wear resistance as well as for rebuilding worn parts. A thin nickel plate is sometimes applied prior to hard chrome plating.

Sacrificial cadmium and zinc coatings are normally applied to protect the basis metal, typically iron or steel. A thin surface coating is normally applied to provide corrosion protection, improve wear or erosion resistance, reduce friction, or for decorative purposes. Since cadmium is significantly more expensive and toxic than zinc, it is used as a protective electroplate only in those circumstances in which its special properties are required.

Cadmium is often selected over zinc as a protective coating in military applications for the following reasons: (1) it is more easily soldered than zinc; (2) its corrosion products do not swell and are not bulky, unlike the "white rust" formed by zinc, and hence do not interfere with functional moving parts; (3) cadmium plating is easier to

**Metal Plating
Related Modifications**

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3.5.3 Solvent Cleaning and Degreasing

The most promising process for recycling cleaning solvents is on-base distillation. It has been shown to be a net cost saver and easy to implement and operate at several locations. However, to function properly, it does require successful solvent segregation. Also, some recycled solvent may not meet original specifications and may have to be reused on less sensitive processes. There may be instances where off-base recycling or manufacturer take-back would be a better solution. These will have to be evaluated on a case-by-case basis.

One of the key elements to successful solvent recycling is management support. Successful recycling requires extensive coordination and cooperation with the solvent purchasers, users, and reprocessors. Traditional disposal procedures, such as disposing of all solvents in a single container, will have to be modified to ensure solvent segregation. Cleaning procedures may have to change as well because recycled solvents may not meet the specifications of the original solvent.

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few substrate surfaces too soft to be blasted. These surfaces account for only a very small fraction of the total surfaces stripped.

Hill AFB Plastic Media Stripping Facility is a model system which can be readily adapted to all facilities. Recommendations for a standard system design are described in the Hill AFB Case Study, Section 3.4.1. This approach would provide a standard package based on a proven design and predictable costs.

3.5.2 Painting

Painting alternatives to reduce hazardous wastes require an integrated approach considering all criteria: corrosion and surface protection requirements; available paint systems; type, size, and number of items being painted; facility conditions, such as temperature and humidity; and existing paint equipment and facility layout. Because of these diverse criteria, consideration of painting alternatives will require a site-specific approach. However, in general the most promising alternative technologies which should be considered and their key advantages are as listed in Table 3-11.

Table 3-11
ALTERNATIVE PAINTING TECHNOLOGIES

Alternative Technology	Key Environmental Advantages
1. Electrostatic Dry Powder Coating	Eliminates most solvent air emissions Minimizes solvent use in cleanup Eliminates overspray paint wastes
2. Waterborne Coatings	Minimizes solvent air emissions Minimizes solvent use in cleanup
3. Compliance Coatings	Minimizes solvent air emissions
4. High-Solids Coatings	Minimizes solvent air emissions
5. Improved Painting Techniques Airless Spraying Conveyor System Robotics	Minimizes solvent use in cleanup Minimizes overspray paint wastes

Process Modification Description

Approximately 15 to 20 TCE vapor degreasers are being used at Anniston Army Depot. Personnel at Anniston previously evaluated the use of 1,1,1-trichloroethane as a replacement for TCE as a vapor degreaser. One tank was operated using 1,1,1-trichloroethane for a 6-month trial period; however, the compound failed to clean parts as well as TCE, and its use was discontinued.

All of Anniston's vapor degreasing tanks are equipped with a distillation solvent recovery system. The stills recover TCE from the solvent-oil mixture for reuse in the degreasers. Most stills at Anniston are manufactured by Detrex Corporation. The stills operate continuously when the vapor degreasers are in operation, normally 8 hours per day, 5 days per week. Dirty solvent is fed from a degreaser boiling sump through a water separator to the recovery still. The steam-heated stills have the capacity to recycle 20 gallons per hour of TCE.

Process Modification Experience

Anniston Army Depot has reported no problems in the operation and maintenance of the distillation units. Twice a year during shutdown the vapor degreasers and stills are taken out of service for cleaning and general maintenance. Vapor degreaser TCE baths have never been dumped during normal operation or shutdown. Losses of TCE are due to drag-out, evaporation, and waste still bottoms.

Still bottoms are automatically discharged to waste holding drums. Still bottoms have typically contained 11 to 17 percent TCE, oils, greases, and dirt. This hazardous waste has been sent to a commercial contractor for treatment. Anniston has investigated if it would be cost-effective to recover TCE from still bottoms. It was determined that the still bottoms would have to contain 40 percent TCE before it would be economical to recover additional solvent.

3.5 Solvent Recommendations

3.5.1 Paint Stripping

Plastic media stripping is the best alternative to replace conventional solvent/chemical stripping. This process eliminates almost all of the environmental problems (hazardous waste, wastewater, and air emissions) associated with solvents. The process has proven to be more effective in removing paint and coatings from surfaces than the solvents, with significant cost savings in labor, materials, and energy. The only limitation in using plastic media concerns the

not fractionate the components, everything that vaporized below the cutoff temperature was distilled and combined. Segregation of the waste heptane from the other organic fluids could have alleviated these off-spec properties. Also, the sediment level, which was slightly above the specification, may be the result of improper cleaning of the still and associated piping prior to startup. Even though it did not meet specifications for calibration fluid, the recycled heptane may have been suitable for some other use.

The use of direct steam injection produced an undesirable secondary wastewater stream that was saturated with the recovered organic fluids. This waste stream could have been eliminated by using an indirect method of heating the waste organic fluid mixture in the still pot.

3.4.10 TCE Recycling at Anniston Army Depot

Industrial Process Description

Anniston Army Depot, constructed in 1941, is a government-owned, government-operated (GOGO) industrial facility, employing approximately 4,500 people. The principal mission of the facility is to recondition used tanks and other armored vehicles. Approximately 700 tanks are reconditioned at the facility each year.

Reconditioning consists of complete disassembly of the tanks and dismantling of their components. Paint, rust, and dirt are removed from these components prior to remanufacturing. Paint is removed by sand blasting or stripped using organic solvents or alkaline strippers. Greases and oils are removed using solvent vapor degreasers, followed by alkaline cleaners. Rust and oxide films are removed by sand blasting and acid pickling.

Solvent vapor degreasing is an effective and economical process for cleaning oils and greases from metallic and other suitable surfaces. Trichloroethylene (TCE) is commonly used in vapor degreasers for the removal of semi-cured varnish or paint films, heavy rosins, and buffering compounds (33). To clean printed circuit boards, electronic components, and electrical motors, 1,1,1-trichloroethane is used. Methylene chloride and perchloroethylene are also used in some vapor degreasing operations. In general practice, 1,1,1-trichloroethane is the most widely used solvent today because of its economical cost, low solvent consumption, and low energy requirements. This solvent also has a higher acceptable OSHA vapor exposure limit and is exempt from air pollution regulations in most states (33). The other solvents are used when their special properties (e.g., lower or higher boiling point) are required for specific cleaning applications.

Heptane was stored in underground tanks and recirculated through test stands. Waste heptane and other organic fluids used in this building were mixed and stored in an underground waste storage tank. This mixture of waste organic fluids was donated to Brookhaven National Laboratories for boiler fuel. An onsite waste blending facility would not accept this waste because its flash point was below acceptable limits.

Process Modification Description

A nonfractionating, batch, atmospheric distillation system, manufactured by Solvent Purification Systems of Indianapolis, Indiana, was installed to reclaim heptane from the underground waste storage tank. The system used live steam injected directly into the pot to heat the waste organic fluid mixture. Distillate passed through a demister into a water-cooled condenser. This system produced a two-phase (water and organic) condensate, which was separated in a decanter. The system was designed to produce up to 50 gallons per hour of distillate.

Process Modification Experience

One batch of waste organic fluid was processed through the still three times in an attempt to meet specifications for calibration fluid. This reprocessed organic fluid failed to meet three specifications for Type II calibrating fluid: the initial boiling point was 264°F versus a minimum acceptable boiling point of 300°F; the flash point was 87°F versus a minimum of 100°F; and the sample contained 1.2 mg/L of sediment versus a maximum limit of 1.0 mg/L. Waste organic fluid was distilled at a rate of 12 gallons per hour during the test.

This still was given to the facility by higher command with instructions to use the still to recycle solvents. Local personnel were not involved in the decision to recycle solvents or to select the type of still to be used. Without this involvement, a poor choice of application was made. A non-fractionating still cannot separate a mixture of solvents into their useful components.

Future Direction

The still has not been used since the initial attempts to recover heptane for calibration fluid in February 1983. Although the reprocessed heptane failed to meet specifications, several of the contributory causes were unrelated to the equipment. For example, the reprocessed heptane probably failed to meet the initial boiling point and the flash point specifications because lighter organic fluids were mixed with the waste heptane. Since this still could

of an undetected internal still leak and a buildup of iron oxide in the system during periods of nonuse.

Since the recycled solvent did not meet specifications, it could not be accepted by the base supply department for distribution and reuse. Most of the recycled solvent was, however, reused in the tire shop, which did not require solvent that met the specifications. Some of the solvent bypassed the supply department and was sent directly to users who expressed an interest in the free material. Although maintenance personnel at the tire shop were pleased with the quality of the recycled Stoddard solvent, they noticed that the recycled material took longer to dry than fresh Stoddard solvent.

No major problems were usually encountered during operations. During two runs, however, the still was shut down briefly because the waste Stoddard solvent was contaminated with MEK and hydraulic fluid. A normal batch run required a single operator for 8 hours. Two-man crews were used for safety and training.

The system had one inconvenient design flaw. Since the still sat on grade, the waste bottoms could not flow directly into a 55-gallon drum. The waste had to be emptied into a 5-gallon can and then transferred to a drum. This problem could have been alleviated if the still had been elevated 3 feet.

Future Direction

Operation of the still was discontinued because of its limited use, off-spec product quality, and resultant poor economic performance. The still was given to Robins AFB in Macon, Georgia, to supplement their existing solvent recovery unit.

3.4.9 Heptane Recovery At Norfolk NARF

Industrial Process Description

Norfolk Naval Air Rework Facility (NARF) uses heptane as a calibrating fluid for aircraft fuel flow sensors. Heptane was used as a substitute for jet fuels JP-4 and JP-5 because it exhibited similar properties yet had a more consistent composition from batch to batch than jet fuel. It has been of vital importance to maintain this consistency in order to calibrate the fuel flow sensor with a known standard; therefore, stringent specifications exist for this calibration fluid. About 25,000 gallons of heptane have been used at this facility each year.

Vapors were condensed in a water-cooled condenser. The liquid then passed through a moisture absorption tank filled with cotton rags and finally to a clean solvent storage tank or a 55-gallon drum.

Process Modification Experience

The solvent recovery system cost approximately \$50,000 to purchase and install. The cost savings dropped from \$3.72 per gallon of solvent recovered in 1982 to \$1.44 per gallon in 1983, primarily as a result of a dramatic drop in the price of fresh Stoddard solvent from \$4.51 per gallon to \$1.90 per gallon over the same period (32). Only 4,500 gallons of Stoddard solvent were reclaimed, resulting in a cost savings of approximately \$7,000.

The poor economic performance was the result of the system's being underutilized. The quantities of solvent recycled were less than anticipated for the following reasons:

1. Many of the original users switched to a different cleaning solution.
2. It was difficult to collect, transport, and store the waste Stoddard solvent that was being generated in the numerous small shops. Maintenance personnel continued to dump the waste solvent into the sanitary sewer or into a common slop drum for disposal.

Also contributing to the poor success of the collection system may have been the inadequate involvement and commitment of the operational personnel. The concept was developed by an outside group and implemented as a research project. In addition, management's commitment to the success of the project was not as evident as for a similar system implemented at Warner Robins AFB.

Of the 19 shops that used Stoddard solvent in 1981, only the tire shop actively collected and stored waste solvent for recycle. This shop used two 300-gallon dip tanks that contained Type II PD-680 Stoddard solvent. The cleaning solution removed carbon, grease, and grit from aircraft wheel bearings. Every 4 months the spent Stoddard solvent was discharged into ten 55-gallon drums. The waste solvent in the drums was then pumped to the still holding tank for recycling.

The still was operated nine times since 1981, approximately 1 day every 4 months. An average of 506 gallons of solvent was recycled at a recovery rate of 97 percent during each of the nine runs. Samples of the recycled solvent were analyzed and generally failed to meet specifications because

reduced the small quantities exclusion limit from 1000 kg to 100 kg per month, to take effect in March 1986. Many small electroplating and surface finishing shops will then have to comply with the new RCRA requirements; however, few military industrial facilities will be affected since most of them are large waste producers and thus are already required to follow EPA regulations.

EPA is also required to promulgate new regulations which will ban the landfilling of bulk or noncontainerized liquids and severely restrict the land disposal of other hazardous wastes. The regulations are expected to motivate DOD facilities to implement alternative hazardous waste disposal practices, such as incineration.

Wastewater Pretreatment Requirements

The EPA has established "National Categorical Pretreatment Standards" that limit wastewater contaminant concentrations which can be discharged to publicly owned treatment works. In July of 1983, final regulations (40 CFR 413 and 433) were issued for the metal finishing point source category. These pretreatment regulations pertain to the following operations: electroplating, electroless plating, chemical etching and milling, anodizing, conversion coating, and printed circuit board manufacture.

For regulatory purposes, EPA has divided the electroplating industry into two major groups: "captive facilities," which own the material they process, and "job shops," which do not. DOD electroplating shops fall into the first category. Most DOD electroplating shops are further defined by EPA as "integrated" facilities because electroplating waste streams are combined with other waste streams before treatment and discharge. "Nonintegrated" facilities are defined by EPA as those which have significant wastewater discharges only from an electroplating shop. Job shops, nonintegrated captive facilities, and captive facilities were required to meet interim pretreatment standards by June of 1984.

Table 4-2 presents the final pretreatment limitations for the metal finishing category of electroplaters. Pollutants of concern include toxic metals, cyanide, and toxic organics. The compliance date for these standards is February 15, 1986. State and local regulatory agencies are required to administer and enforce these regulations and are allowed to implement more stringent standards than the federal pretreatment limits.

Table 4-2
EPA METAL FINISHING SUBCATEGORY
PRETREATMENT STANDARDS FOR EXISTING SOURCES (mg/L)

<u>Constituent</u>	<u>Maximum for Any 1 Day</u>	<u>Maximum Monthly Average^a</u>	<u>Long-Term Concentration Average^b</u>
Cadmium (Total)	0.69	0.26	0.13
Chromium (Total)	2.77	1.71	0.572
Copper (Total)	3.38	2.07	0.815
Lead (Total)	0.69	0.43	0.20
Nickel (Total)	3.98	2.38	0.942
Silver (Total)	0.43	0.24	0.096
Zinc (Total)	2.61	1.48	0.549
Cyanide (Total)	1.20	0.65	0.18
Cyanide (Amenable) ^c	0.86	0.32	0.06
TTO ^d	2.13	--	0.434

^aMonthly average of 10 samples.

^bEPA guidelines to be used as a design basis; not a limitation.

^cFor facilities with cyanide treatment, upon agreement with the pollution control authority, cyanide amenable to alkaline chlorination may be substituted for total cyanide.

^dTotal toxic organics (TTO) refers to the summation of all values greater than 10 micrograms per liter for the toxic organics listed in 40 CFR 413-11.

Wastewater Treatment For Direct Discharge

In September of 1984, EPA promulgated final amended National Pollutant Discharge Elimination System (NPDES) regulations for the direct discharge of pollutants in waterways. The NPDES has put forth an extensive effort to regulate the discharge of toxic pollutants, including development of the NPDES Toxic Control Strategy. One element of this strategy is that all industrial dischargers, including military industrial facilities, must report quantitative data for any toxic pollutant that they know or have reason to believe is present in the discharge above 10 ppb. This requirement is designed to ensure that the permitting authority receives adequate information to make appropriate judgments about the establishment of permit limitations and testing requirements.

NPDES permit limitations are generally based upon promulgated EPA effluent limitation guidelines (technology-based limits) and/or state water quality standards (water quality-based limits). NPDES permits are issued case-by-case by EPA or the state regulatory agency, and the concentration limits specified in the permit are based on one or more of the following: best available technology economically achievable (BAT), flow rate of receiving waters, quality of receiving waters, and pollutant volume and concentration of industrial discharge.

4.2.2 Problem Definition--Metal Plating

Following plating, parts are rinsed to remove plating solution that adhered to the parts (drag-out). Most military plating operations use single overflow rinse tanks that operate at flow rates of from 2 to 8 gallons per minute. Rinsewater flows are typically the predominant sources of wastewater at military plating facilities. Additional discharges of hazardous waste include: cleanup of spills; aerosol spray from such operations as chromium plating that is exhausted to the atmosphere or removed by wet scrubbers; and discarded process solutions.

Wastewaters from plating facilities can be segregated into four waste streams: chromium wastewaters, cyanide wastewaters, non-cyanide wastewaters, and acid/alkali wastewaters. Figure 4-1 shows processes used to treat these various waste streams.

Hexavalent chromium is commonly used in chromium plating bath formulations and is a major concern in the design of waste treatment processes for chrome plating facilities. Chromium must be reduced to its trivalent state before it can be removed by precipitation as a hydroxide. Reduction is normally carried out at an acidic pH, utilizing a reducing agent, such as sodium metabisulfite, sulfur dioxide, or ferrous sulfate. The resulting trivalent chromium can then be removed by hydroxide precipitation with the other plating metals in an industrial wastewater treatment plant. This complicates and adds significantly to the cost of treatment. Ion exchange and electrostatic treatment methods are more expensive alternative treatment processes.

Cyanide wastewaters are typically the product of cadmium and zinc plating, since these metals are typically plated from alkaline cyanide baths. Unfortunately, cyanide baths are dangerous to operate and the resulting cyanide-containing wastes are complicated and costly to treat. The cyanide is typically oxidized at an alkaline pH, using chlorine or sodium hypochlorite.

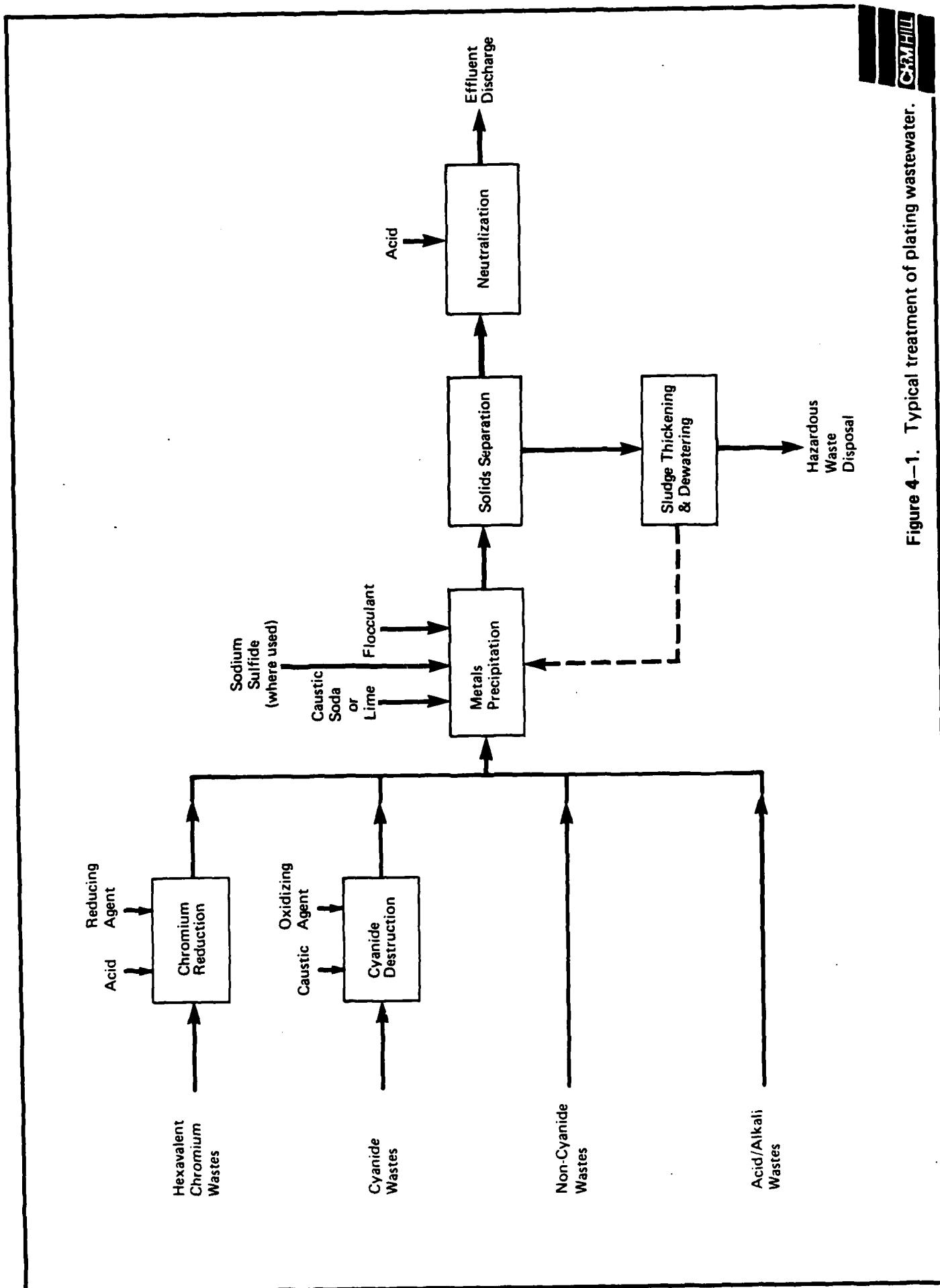


Figure 4-1. Typical treatment of plating wastewater.

Non-cyanide wastewaters are usually those produced in nickel plating. Acid/alkali wastes are produced in metal cleaning and etching operations. These wastes can normally be treated directly for metals removal by hydroxide precipitation.

Following separate treatment for hexavalent chromium reduction and cyanide oxidation, the four waste streams are typically combined for metals removal by hydroxide precipitation. Precipitation as sulfides has been proposed due to the low solubility of most metal sulfides. The resulting solids are typically removed by gravity settling and filtration.

In a review of Army plating operations, Chesler (1) found that 23 DARCOM installations perform metal plating or finishing operations, with wastewater productions varying from less than 100 gallons per day (gpd) to over 150,000 gpd. Metals plated at these facilities include chromium, cadmium, nickel, zinc, tin, lead, brass, and gold. Chesler found that the principal sources of hazardous waste generation at Army plating facilities were drag-out to rinsewater, spills of plating solutions, disposal of acid and alkaline cleaners, and occasional plating bath dumps.

Metal finishing processes were being used at more than 70 Navy facilities, according to a report by Centec Corporation (2). The largest naval electroplating operations were found at Naval Air Rework Facilities (NARFs), Naval Shipyards (NSYs), Naval Air Stations (NASs), the Naval Ordnance Station (Louisville, KY), and the Naval Avionics Center (Indianapolis, IN). Metals plated included copper, chromium, cadmium, nickel, tin, lead, zinc, brass, gold, silver, iron, and rhodium. Wastewater production at the facilities varied from less than 100 to 360,000 gpd. The total wastewater effluent from these metal finishing shops was estimated to be over 3.6 million gpd.

Rinsewaters were found to be the greatest source of wastewaters at Navy plating facilities. Due to low production rates, long plating times, excessive water use, and lack of countercurrent rinsing, Navy rinsewaters were found to be much more dilute than those in commercial operations (2). Concentrations of metals ranged from 0.2 to 2 mg/L compared with 10 to 1,000 mg/L found in commercial facilities.

Process solutions disposed of were primarily spent alkaline and acidic cleaners used to condition parts prior to plating and to remove metal deposits from rejected or damaged parts. These discarded solutions contained significant concentrations of metals and cyanide due to drag-in from previous process cycles and attack of the basis metals by

the chemicals in the cleaning solutions. Navy experience has indicated that the concentration of metals and cyanides in stripping solutions usually exceeds 50,000 mg/L (2).

Another significant contribution of metals and cyanide was the disposal (dumping) of plating baths that failed to perform as required. Dumping of plating baths is rarely practiced in private industry, due to the high costs of chemical replacement and disposal. However, it was reported that many Navy shops dumped plating baths (especially chromium) once or twice a year, usually before plating quality deteriorated, either on a pre-set schedule or based on observation (2).

Most Navy plating shops drum spent plating baths and have a contractor haul these wastes to a permitted hazardous waste treatment/disposal site. Some shops slowly bleed these concentrated wastes to the industrial wastewater treatment plant. Plating baths are also discharged accidentally due to overflow of process tanks, which is aggravated by a lack of high level alarms and adequate operator attentiveness. Because of accidental bath dumps, the total volume dumped exceeds that planned at Navy plating facilities (2).

For hard chrome plating operations, bath dumping is usually the principal source of chromium discharge. Drag-out to rinse tanks is minimized due to the extended plating times of from 24 to 48 hours. Chromium drag-out from a typical Navy plating bath was found to be approximately 100 pounds per year (3). It was estimated that the amount of chromium dumped in plating baths at Pensacola NARF was over 20,000 pounds per year, or approximately 170 times the amount lost to drag-out (2). This is in contrast to decorative chromium plating operations, where parts remain in the plating tanks for a minute or less, and drag-out can exceed 35,000 pounds of chromium per year (3). Impurities generated in the plating process are removed with this drag-out, reducing or eliminating the need for bath dumping.

Plating wastewater treatment sludges are classified (listed) as hazardous. The cost of sludge disposal from Navy facilities was reported to range from \$113 to \$320 per ton (2), which has amounted to an annual disposal cost of hundreds of thousands of dollars per facility.

The Air Force was reported to operate 15 electroplating facilities (4). These facilities ranged from the small, three to four plating bath operation, to the very large operation with over 40,000 square feet of floor space. These shops plated a variety of metals in support of both local maintenance and periodic major overhaul of engines and aircraft at Air Logistics Centers (5). In addition, plating was performed by private contractors at government-owned, contractor-operated (GOCO) facilities.

4.3 Technologies Available to Reduce Hazardous Wastes from Metal Plating

Several process modifications have been proposed to reduce the generation of hazardous metal plating wastes at their source. These include improved housekeeping practices, reducing drag-out and modifying rinsing, recovering metals from rinsewaters, reduction or elimination of tank dumping, and changing to less hazardous plating materials. Each of these modifications is discussed in detail in this section of the report.

4.3.1 Housekeeping Practices

Production rates can be increased, product quality can be improved, and hazardous wastes can be decreased by improving housekeeping practices. Although good housekeeping requires little or no capital investment, significant savings in raw material usage and wastewater treatment can be realized. The following list of housekeeping practices, although not all-inclusive, could save plating shops thousands of dollars a year:

1. Repair all leaking tanks, pumps, valves, etc.
2. Inspect tanks and tank liners periodically to avoid failures that may result in bath dumps. Inspect steam coils and heat exchangers to prevent accidental contamination of steam condensate and cooling water or leakage of condensate and cooling water into the plating bath.
3. Install high level alarms on all plating and rinse tanks to avoid accidental bath dumps.
4. Maintain plating racks and anodes to prevent contamination of baths. Remove racks and anodes from baths when not in use.
5. Minimize the volume of water used during cleanup operations.
6. Properly train plating personnel so that they understand the importance of minimizing bath contamination and wastewater discharge.
7. Properly clean and rinse parts prior to plating to minimize contamination of the plating bath. Areas that are not to be plated should be masked or stopped off with tape or wax to limit corrosion from these areas. Parts should be removed from the bath when not being plated.

4.3.2 Drag-out Reduction

To evaluate the effectiveness of drag-out reduction, existing drag-out must be quantified. For example, the drag-out from barrel plating tanks is usually ten times greater than that removed from baths employing rack plating. The shape and design of the parts, racks, and barrels can also significantly affect drag-out rates.

It is clear that modifications should first be implemented to reduce bath dumps before concentrating on reducing drag-out. A more favorable rate of return is realized by implementing drag-out reduction techniques at decorative chrome, cadmium, and zinc plating lines, where plating times are relatively short and drag-out is significantly greater than in hard chrome plating.

Drag-out can be reduced by decreasing either bath viscosity or surface tension. Viscosity can be reduced by reducing the chemical concentration of the bath or by increasing temperature. Surface tension can be reduced by either adding non-ionic wetting agents or increasing bath temperature. These modifications improve the drainage of plating solutions back into plating baths or reduce the concentration of metal in the drag-out. Lowering the velocity of withdrawal of parts from a bath can drastically reduce the thickness of a drag-out layer, due to surface tension effects.

Drag-out can be captured by the use of drain boards, drip bars, and drip tanks and returned to the bath (Figure 4-2). These simple devices save chemicals, reduce rinse requirements, and prevent unnecessary floor wetting (7). Significant drag-out reduction can be accomplished if platers carefully rack and remove parts so as to minimize entrapment of bath materials on surfaces and in cavities.

Air knives can be used to knock plating films off parts and back into process tanks. This technique is particularly effective in removing ambient temperature solutions from plated parts. Spray rinses are also effective in removing drag-out from parts. The part is held over the plating tank and sprayed with rinsewater. Over 75 percent of plating chemicals drain back to the plating bath. Spray rinsing is best suited for flat parts that are hard chrome plated since evaporation rates in these baths can exceed rinsewater requirements (8).

4.3.3 Rinsewater Modifications

Reduction in rinsewater flows may not reduce the amount of toxic metals to be disposed of, but it can reduce the volume of liquid waste that must be processed in industrial wastewater treatment plants. However, concentrations of metals would increase, resulting in possible adverse impacts

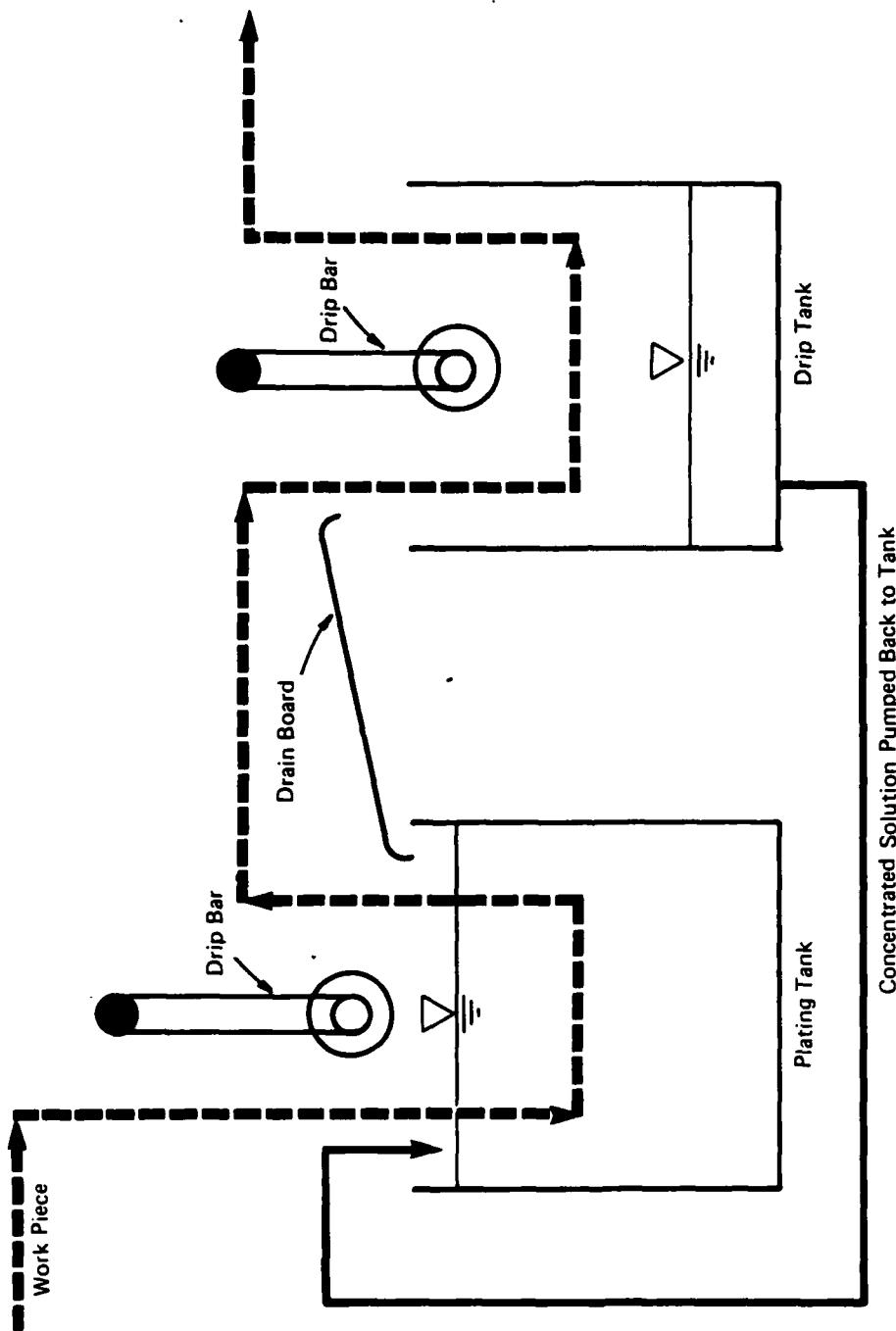


Figure 4-2. Drag-out recovery devices.

on treatment. Thus costs of wastewater treatment may not be appreciably reduced, especially if treatability is impaired.

If the rinse flow rates are reduced sufficiently, it is possible to utilize rinsewater to make up for evaporative losses in the plating tanks, resulting in metal recovery and reduced waste discharge. Reducing flows can also increase the efficiencies of metal recovery processes, such as ion exchange, electrodialysis, and reverse osmosis.

The following are descriptions of techniques that have been developed to improve rinse efficiency.

Spray or Fog Rinse

This method can be used to improve the efficiency of rinsewater use. Drainage can be directed back into the process tank if evaporation is sufficient, or into a drag-out tank.

Still or "Dead" Rinse Tanks

These can be used prior to flowing clean water rinse tanks. Water from the drag-out tank or still rinse tank can be returned to the bath to make up for evaporation losses. Increasing plating bath temperatures to increase evaporation may be justified.

Rinse Tank Mixing

This technique can increase the efficiency of water use (Figure 4-3). A submerged influent water line evenly distributes fresh water through the tank and creates a rolling action, enhanced by aeration. Existing facilities can be retrofitted with these modifications using inexpensive PVC piping.

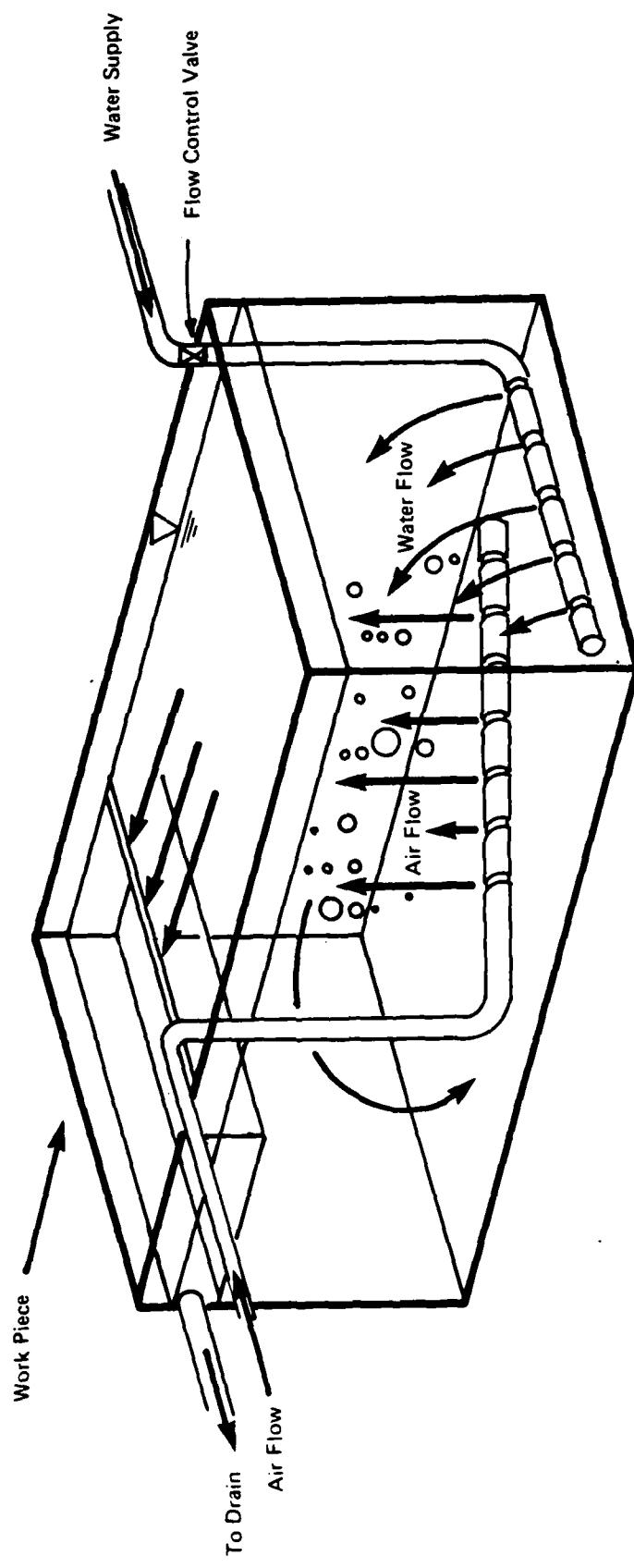
Water Supply Control Valve(s)

In the interest of reducing rinsewater flows to the minimum, these inexpensive devices (approximately \$30) regulate the feed rate of fresh water within a narrow variation of flow despite variations in line pressure. These controllers can usually be set to regulate flow within a 1/2-gpm range.

Conductivity Controllers or Timers

These can be used to operate rinsewater control valves, thereby reducing demands on plating personnel. Conductivity control operates on the principle that clean water has a lower conductivity than water contaminated with plating solutions. Timer controls operate on a preset cycle. Conductivity control is preferable when the amount and type of work varies greatly from day to day. Timers are adequate when production is reasonably uniform. A conductivity

Figure 4-3. Improved rinse tank design.



probe, controller, and valve reportedly can cost less than \$1,000 to purchase and install (9). Conductivity controllers have been installed in many Navy and Air Force plating shops. Unfortunately, these units have not performed well in most installations, resulting from the probes' lack of ruggedness and need for frequent calibration and cleaning. In addition, many controllers are constructed of materials subject to corrosion. Also, selecting the optimum minimum and maximum conductivity setpoints can be difficult. Many platers have overridden or disconnected these conductivity controls due to dissatisfaction with their operation.

Cascade Rinsewater Recycling

In this technique, overflow from one rinse tank is used as the water supply for another compatible rinsing operation. For example, rinsewater effluent from an acid dip tank can be cascaded to an alkaline cleaner rinse tank. Interconnecting rinsing tanks can complicate operations, but the cost savings often exceed the additional operation cost.

Countercurrent Multiple Rinse Tanks

This arrangement can reduce rinse flows by over 95 percent compared to single overflow rinses. Optimum countercurrent rinsing usually employs three tanks operating in series, with parts sequentially immersed in each of the three tanks, countercurrent to the rinse flow (Figure 4-4).

The concentration of plating solution in each successive rinse tank can decrease by a factor of ten. For example, assume that the drag-out concentration of a plating bath contains 40,000 mg/L of dissolved solids, and the final rinse is limited to 40 mg/L. Concentrations of dissolved solids in the three multiple rinse tanks could be controlled to 4,000, 400, and 40 mg/L. For a drag-out rate from the plating bath of 1.0 gal/hr, a countercurrent rinse flow of 10 gal/hr would be sufficient, as compared to 1,000 gal/hr for a single rinse tank.

Many military facilities do not include countercurrent rinsing because the required additional space is often not available, and because of the additional production time since parts must be rinsed at more than one tank. Where space is available, the cost of additional rinse tanks can range from \$1,000 to \$10,000 per tank, depending upon size, shape, and materials of construction.

Countercurrent rinse systems can be retrofitted in existing tanks by adding baffles, weirs, pipes, and pumps. Savings vary considerably due to differences in costs of raw water

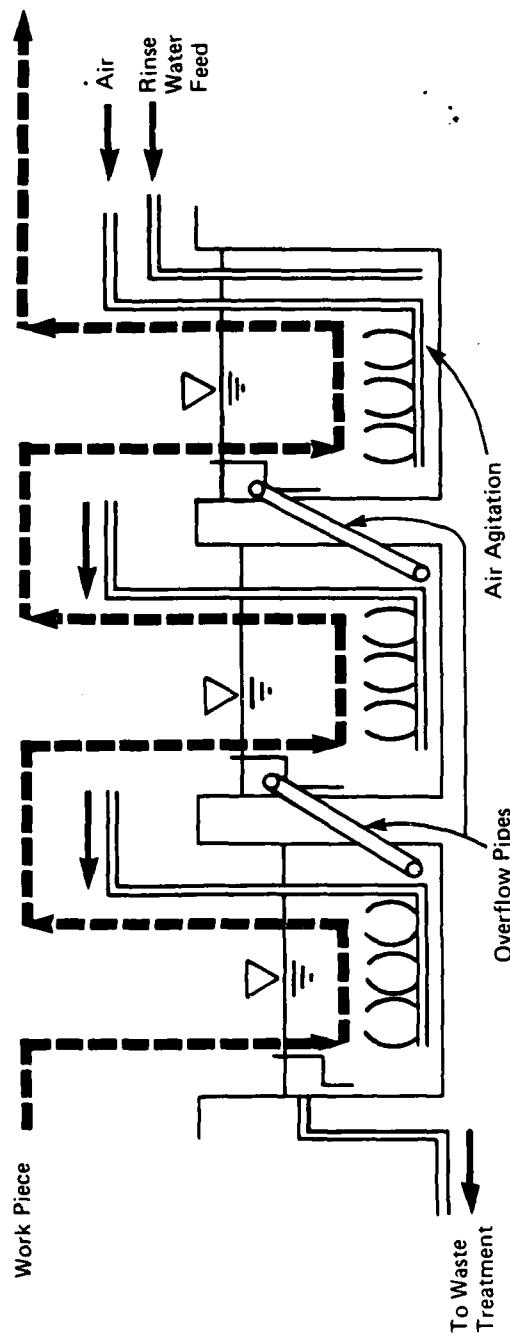


Figure 4-4. Three-stage countercurrent rinse system.

and wastewater treatment. At many facilities, the payback period can be as short as one year. Further savings can be realized when plating solution is recovered by returning the most concentrated rinsewater to the plating bath to make up for evaporative losses. Similar savings can be accomplished by employing a "dead" or "still" rinse, followed by a flowing rinse. The contents of the still rinse are periodically returned to the plating bath to recover the plating chemicals.

4.3.4 Chemical Recovery Processes

Evaporation, reverse osmosis, ion exchange, electrodialysis, Donnan dialysis, and coupled transport have been used to recover chemicals from rinsewaters. These processes reconcentrate plating solutions from rinsewater and produce a relatively pure water, which is reused for rinsing. Both general and site-specific factors must be evaluated to determine the recovery process which is best suited for a particular plating operation. Factors include: the metal being plated, drag-out rates, rinsewater concentrations and flows, space requirements, manpower requirements, availability of utilities (steam, electricity, etc.), and costs for water and wastewater treatment and sludge disposal.

Evaporation

Evaporation is the oldest method used to recover plating chemicals from rinse streams. In this process, enough rinsewater is boiled off to concentrate the solution sufficiently to be returned to the plating bath. The steam is then condensed and reused for rinsing. Evaporators are operated under a vacuum to lower the boiling temperature in order to reduce energy consumption and prevent thermal degradation of plating additives.

Because of their high energy use, evaporators are most cost-effective in concentrating rinsewaters that are returned to hot baths, such as those used in chromium plating, where high evaporation rates reduce the concentration required. However, evaporative recovery has been used for ambient temperature nickel baths and various metal cyanide baths. The capital and operating costs of an evaporator can be reduced by employing countercurrent rinsing to produce a low-volume, concentrated rinse stream. One study estimated that chrome plating shops at Naval shipyards could save \$17,000 a year (1983 dollars) by employing a countercurrent rinse system in conjunction with evaporative recovery (10). The payback period was estimated to be less than one year.

In order to maintain a "zero discharge" or "closed loop" system, it is necessary to periodically remove impurities

unnecessary to add sodium bisulfite or other reducing agents in waste treatment for conversion of hexavalent to trivalent chromium prior to precipitation. Trivalent solutions are typically less concentrated (22 g/L versus 150 g/L for hexavalent solutions), thus lessening the amount of chromium dragged out on parts. Consequently, sludge produced from trivalent baths is about one-seventh the volume from hexavalent baths and is far less toxic (24).

The main disadvantage of trivalent solutions is that they cost two to three times more than hexavalent solutions. Some researchers have reported that higher production rates and lower rejection rates can be realized with trivalent chromium plating solutions; however, the main advantage of the solution is the lower cost of wastewater treatment and sludge disposal. Before a plating shop converts to trivalent chrome solutions, a detailed study must be performed to determine if the projected savings in waste treatment are greater than the increased operating cost.

Electroless Nickel

The majority of nickel plating is done in an acidic (pH between 1.5 and 4.5), elevated temperature (between 110°F and 150°F) Watts bath which contains nickel sulfate, nickel chloride, and boric acid. An electrical current causes the nickel to be plated on the substrate.

In 1946, an electroless plating process was developed which coated a substrate without the use of an outside source of electrical current. Electroless nickel plating employs the substrate to catalyze a chemical reduction reaction. However, due to the expense of the chemical reducing agents, electroless plating is not cost effective in applications where conventional electroplating can be used.

The main advantages of electroless nickel plating are that the throwing power is essentially perfect and the deposits provide greater protection of the substrate since they are less porous (8). In addition, the nickel concentrations of electroless baths are approximately one-eleventh those of conventional Watts nickel baths. Therefore, drag-out quantities and sludge production from an electroless bath are much less than from a conventional bath.

4.4 Plating Case Studies

4.4.1 Ion Vapor Deposition of Aluminum at NARF North Island

Industrial Process Description

North Island Naval Air Rework Facility (NARF), located in San Diego, overhauls Navy fighter planes such as F-4s, F-14s, and F-18s and helicopters such as H-46s and H-53s.

has been considerable incentive to develop a substitute for cadmium coatings for corrosion protection. Aluminum coating is a logical choice as a replacement for cadmium to provide corrosion protection, since aluminum is anodic to steel and provides galvanic protection similar to that afforded by cadmium. In addition, its corrosion products are not bulky or unsightly. Aluminum is also cheaper than cadmium and zinc on a volume basis. Moreover, aluminum can be used up to a temperature of 925°F compared with a maximum of 450°F for cadmium. As a result, there has been considerable interest in the possibility of aluminum plating, with many attempts to develop a successful method. However, the electrode potential of aluminum is too negative for it to be successfully plated from an aqueous solution (25). Aluminum has been deposited on steel by hot dipping or using a metal spray system. These methods do not provide the thin, uniform coating required on aircraft parts, nor do these coatings adhere to substrates as strongly as plated cadmium.

As a logical extension of vacuum deposition of cadmium, ion vapor deposition (IVD) of aluminum was developed by McDonnell Douglas Corporation as a means of replacing cadmium plating on steel aircraft parts (26-28). The IVD system (Ivadizer) consists of a vacuum chamber, a resistance heating aluminum vaporization system, and a high voltage system to ionize the aluminum and impart a negative charge to the parts, resulting in aluminum ions electrodepositing on the parts. Air in the vacuum chamber is replaced by a low pressure inert gas, which is ionized. Interaction of aluminum vapor with the ionized inert gas is required for the aluminum to be ionized and be attracted to the oppositely charged parts and coat them uniformly. Without this ionization and interaction with the inert gas ions, IVD would be restricted to line-of-sight coating as in vacuum deposition of cadmium.

Advantages cited for IVD of aluminum include a higher useful temperature, improved throwing power, and better adhesion of the aluminum coating compared to cadmium. In addition, parts which are cadmium plated require baking to prevent hydrogen embrittlement; problems have been encountered with oven temperatures not being carefully controlled, resulting in parts being scrapped. Safer working conditions were cited as another advantage of IVD of aluminum. (A few years ago, an individual at North Island was hospitalized following exposure to cadmium while cleaning a VacuCad chamber. Such an occurrence could be avoided with aluminum.)

Trivalent Chromium Baths

Some platers have investigated using trivalent chromium solutions instead of conventional hexavalent chromium solutions. With trivalent chromium rinsewaters, it is

material substitution may require a considerable capital expenditure. However, the savings in eliminating cyanide treatment can make the modification economically attractive (23).

Parts being plated in non-cyanide cadmium baths can require more thorough cleaning prior to plating than parts plated in cyanide baths. The non-cyanide cadmium baths reportedly have less throwing power and lower cathode efficiency than cyanide baths. Despite the disadvantages, however, some platers prefer the new non-cyanide plating baths because of the reduction in waste treatment complexity. Some have reported that drag-out of cadmium is reduced compared to that experienced with cyanide baths.

Non-cyanide zinc and cadmium baths usually cost more than cyanide baths. However, to properly evaluate the cost effectiveness of the material substitution, the following factors must also be considered: cost of new corrosion-resistant equipment, difference in labor and chemical costs, change in production rate, and savings realized by eliminating cyanide treatment.

In 1983, Charleston Naval Shipyard switched from alkaline cyanide baths to an acidic non-cyanide solution and eliminated the cyanide oxidation process from the waste treatment plant (2).

Vacuum Deposition of Cadmium

Vacuum deposition of cadmium was developed as an alternative to electroplating. Problems with electroplating arise from cadmium cyanide baths due to the toxicities of cadmium and cyanide. Switching to non-cyanide plating baths (discussed above) removes one of these problems. Use of vacuum deposition of cadmium also eliminates the need for cyanide.

Vacuum deposition of cadmium is a line-of-sight process, making it difficult to provide a uniform deposit on an irregularly shaped part. Parts need to be rotated at intervals during processing to produce a more uniform coverage, and adhesion of the deposit to the basis metal is not as strong as that produced by conventional cadmium plating. Also, occupational and environmental hazards can result from the evacuation of cadmium vapors and condensed aerosols. In addition, the vacuum exhaust must be carefully filtered to prevent these cadmium vapors and condensed aerosols from escaping to the work environment.

Ion Vapor Deposition of Aluminum

Due to the many hazards inherent in working with cadmium, and increasingly stringent requirements being placed on disposal of wastes containing even traces of cadmium, there

predicted. However, coupled transport will not be commercially viable until more long-lived membranes are developed.

4.3.5 Material Substitution

Non-Cyanide Baths

Traditionally, cadmium, zinc, brass, and precious metals have almost universally been plated from alkaline cyanide baths, due to the superior plate produced from stable metal cyanide complexes. Unfortunately, cyanide baths are costly and dangerous to operate and the wastes generated are difficult and expensive to treat.

In the late sixties and early seventies, considerable research was performed to develop non-cyanide zinc electroplating baths. As a result, several alternative zinc baths were developed. Alternatives include low cyanide baths, non-cyanide alkaline baths, neutral ammonium chloride and potassium baths, and a number of acidic baths containing sulfate, chloride, and fluoborate ions (8).

Low cyanide baths contain approximately 20 percent as much cyanide as conventional cyanide baths and have similar operating characteristics. However, process control is more difficult and cyanide treatment is still required.

Neutral chloride baths use ammonium or potassium ions for complexing the zinc. These baths usually require the addition of proprietary brighteners and chelating agents which form zinc complexes. Unfortunately, these zinc complexes can be difficult to remove in subsequent waste treatment.

Acid sulfate, chloride, and fluoborate baths have become the most popular non-cyanide zinc baths. With the recent development of new additives, acid zinc baths are capable of producing bright deposits that are competitive with alkaline cyanide baths for general plating applications (8).

Less effort has been expended in developing non-cyanide cadmium baths since the volume of cadmium plating is only 5-10 percent that of zinc plating. Due to increased environmental and safety concerns with operating and disposing of cadmium cyanide baths, alternative proprietary acidic cadmium baths similar to zinc baths have recently been developed to replace cyanide baths.

Most of these acidic baths consist of cadmium oxide, sulfuric acid, distilled water, and anion compounds. Since many old alkaline cadmium cyanide plating tanks are made of bare steel, conversion to these acidic baths may require that the existing tanks be refurbished or replaced. Thus

Laboratory tests have shown that metal ions can be concentrated more than tenfold by Donnan dialysis. The acid solution can be returned directly to the plating bath (21).

The main advantage of Donnan dialysis over ED or RO is its lower energy use. Unfortunately, the recovery solution acidifies the plating bath and contains cationic impurities. Donnan dialysis has not been commercially applied, since existing membranes have short life expectancies. Extensive research is currently being performed to determine the applicability of recovering metals with Donnan dialysis.

Coupled Transport

In coupled transport, similar to Donnan dialysis, ions are driven across a membrane against a concentration gradient. The membrane is microporous, containing a liquid complexing agent held within the pores. Metals combine with this complexing agent and are removed from a dilute solution. On the other side of the membrane is a solution in which metal solubility is favored over that of the complex. The result is transport of a metal across the membrane against a concentration gradient due to the coupling of these two complexation reactions (22).

In field and laboratory tests, coupled transport has been used to recover chrome from decorative chrome plating rinsewaters. Dichromate ions are tied up by an organic amine complexing agent. The complex then diffuses through the membrane. Due to high pH on the other side of the membrane, the complex is broken, leading to the release of chromic acid and regeneration of the amine complex.

According to researchers, coupled transport can be used to save rinsewater and to recover chromium as a pure sodium chromate concentrate. Unlike other recovery processes, the recovered chromium cannot be directly returned to a bath without further processing. However, sodium chromate can be used in the plating shop in cleaning solutions or etchants, or sold for other uses (22).

In field tests, coupled transport membranes have had mixed success. While some membrane modules showed no deterioration in performance during a 4-month period, others quickly developed leaks or clogged due to precipitation of iron hydroxide.

The capital and operating costs of a coupled transport membrane system for the recovery of 5,000 lb/year of chromium (as sodium chromate) from decorative chromium plating were estimated to be \$10,000 and \$6,200/year, respectively (1982 dollars) (6). Net annual savings were estimated to be \$5,700, with a 2-year payback period. Favorable savings for a hard chromium shop were also

Therefore, ED generally can produce a more concentrated solution than IE and RO, eliminating the need for an evaporative concentrator when used for applications with ambient temperature plating baths. ED units are also reportedly easy and economical to operate, require little space, and operate continuously without requiring regeneration (8).

A disadvantage of ED and RO is that all ionic species are nonselectively removed. Therefore, ionic impurities are returned to the plating bath along with the recovered metal, and organic brighteners, wetting agents, and other nonionized compounds accumulate in the dead rinse tank. Therefore, plating baths must be periodically treated to remove impurities and the dead rinse tanks occasionally disposed of.

If the applied voltage exceeds the hydrogen electrode potential, water will be converted to gaseous hydrogen and hydroxide ions. The subsequent increase in pH can cause precipitation of metal hydroxides that can foul the membranes (19).

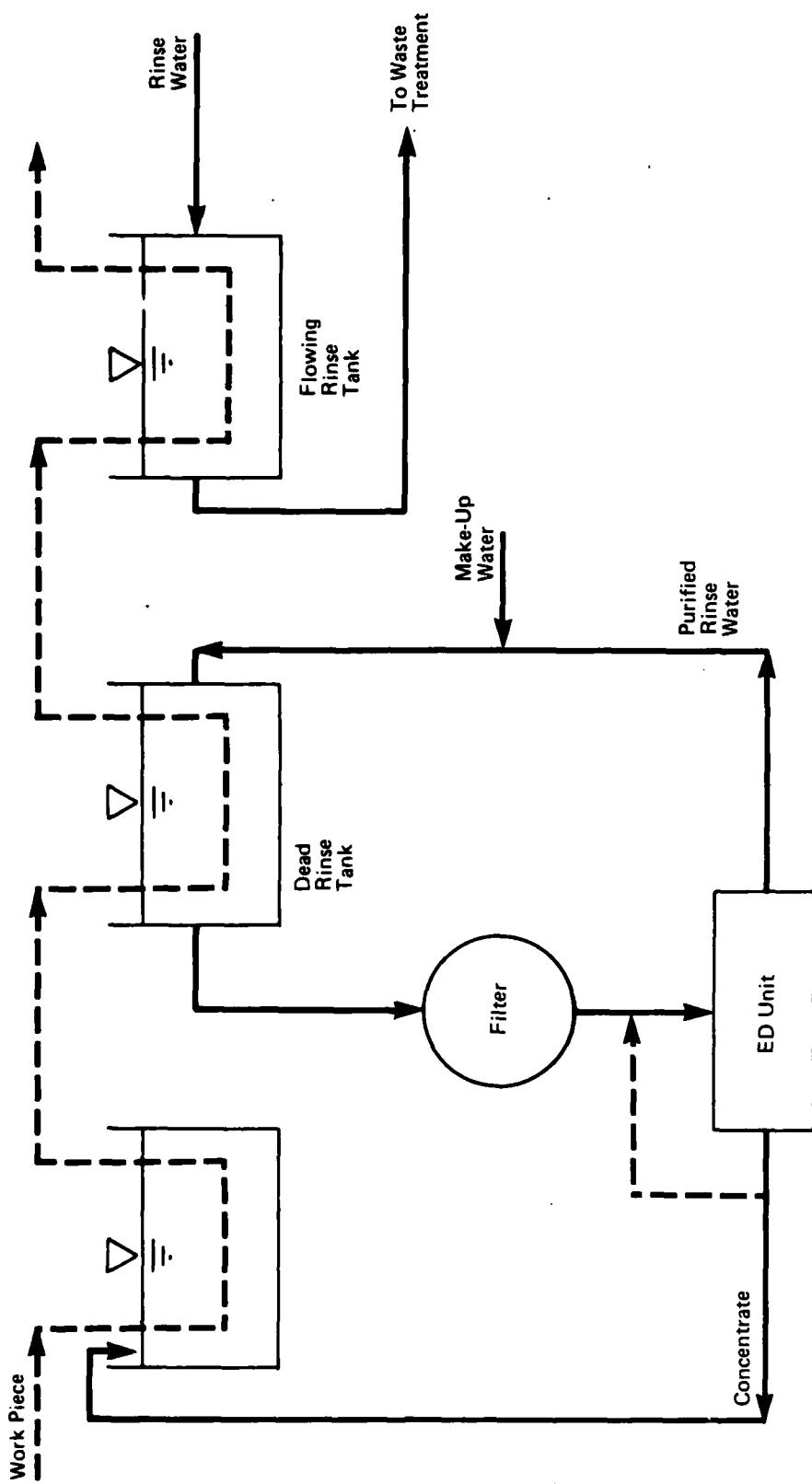
ED package systems cost from \$30,000 to \$45,000 (1984 dollars). A Navy study estimated a less than one year payback period for an ED recovery system for a cadmium cyanide plating bath operating 4,000 hours per year at drag-out rates of 1.3 lb/day of Cd and 5.1 lb/day of Cn. This evaluation did not include the costs of removing impurities from the baths or maintaining the ED units and replacing the membrane modules (8).

An EPA study evaluated recovery of nickel from rinsewaters using ED (20). The ED unit was able to recover 95 percent of the nickel salts from the rinsewater and return the concentrated solution to a Watts-type nickel plating tank. The study estimated that \$16,000 per year could be saved by employing ED in a nickel plating line which operated 4,000 hr/year. The cost estimate only considered savings in chemical usage, wastewater treatment, and sludge disposal, and did not consider the cost of operating and maintaining the ED system.

Donnan Dialysis

Donnan dialysis is a membrane separation process similar to reverse osmosis and electrodialysis. However, rather than relying on high pressure or electrical current to drive ions through membranes, Donnan dialysis employs a concentration gradient. The recovery process is based on the (Donnan) principle that two solutions separated by a membrane will remain electrically neutral, allowing metal ions (e.g., nickel) to be exchanged from a dilute rinsewater with hydrogen ions in a concentrated sulfuric acid solution.

Figure 4-8. Electrodialysis recovery system.



designed to purify plating rinsewaters. The units cost less and require less space than conventional fixed bed systems, and incorporate regenerant chemical reuse techniques to reduce operating cost and yield higher product concentration for recycle. RFIE units have proved effective in three basic applications:

1. Recovery of chromic acid from rinsewaters
2. Recovery of nickel, copper, zinc, tin, and cobalt from rinsewaters
3. Concentration of mixed-metal rinse solution for disposal

Ion exchange has been most successful when recovering chromic acid and nickel from rinsewaters, but problems have been encountered in concentrating mixed-metal solutions. By using the ion exchanged water for rinsing, fresh water consumption can be reduced by 90 percent. However, waste regenerant brine can be difficult and expensive to treat and dispose of. The environmental and economic benefits of reduced water consumption can often be offset by an increased use of treatment chemicals (18).

Electrodialysis

Electrodialysis (ED) concentrates or separates ionic species in a water solution through the use of an electric field and semipermeable ion-selective membranes. Applying an electrical potential across a solution causes migration of cations toward the negative electrode and migration of anions toward the positive electrode. ED units are packed with alternating cation and anion membranes. Cation membranes pass only cations, such as copper, nickel, and zinc, whereas anion membranes pass only anions, such as sulfates, chlorides, or cyanides. Alternating cells of concentrated and dilute solutions are formed between the cation and anion membranes. Packaged ED units contain from 10 to 100 cells.

Electrodialysis has been used to recover cationic metals from plating rinsewaters. In a typical application, as depicted in Figure 4-8, rinsewater from a stagnant or "dead" rinse (i.e., no inflow or outflow) tank is continuously fed to an ED unit and concentrated by a factor of ten. The concentrate is then returned to the plating bath. The waters in the dilute cells are combined with makeup water and returned to the dead rinse tank.

Unlike ion exchange and reverse osmosis, the maximum concentration limit of an electrodialysis unit is only limited by the solubility of the compounds in solution.

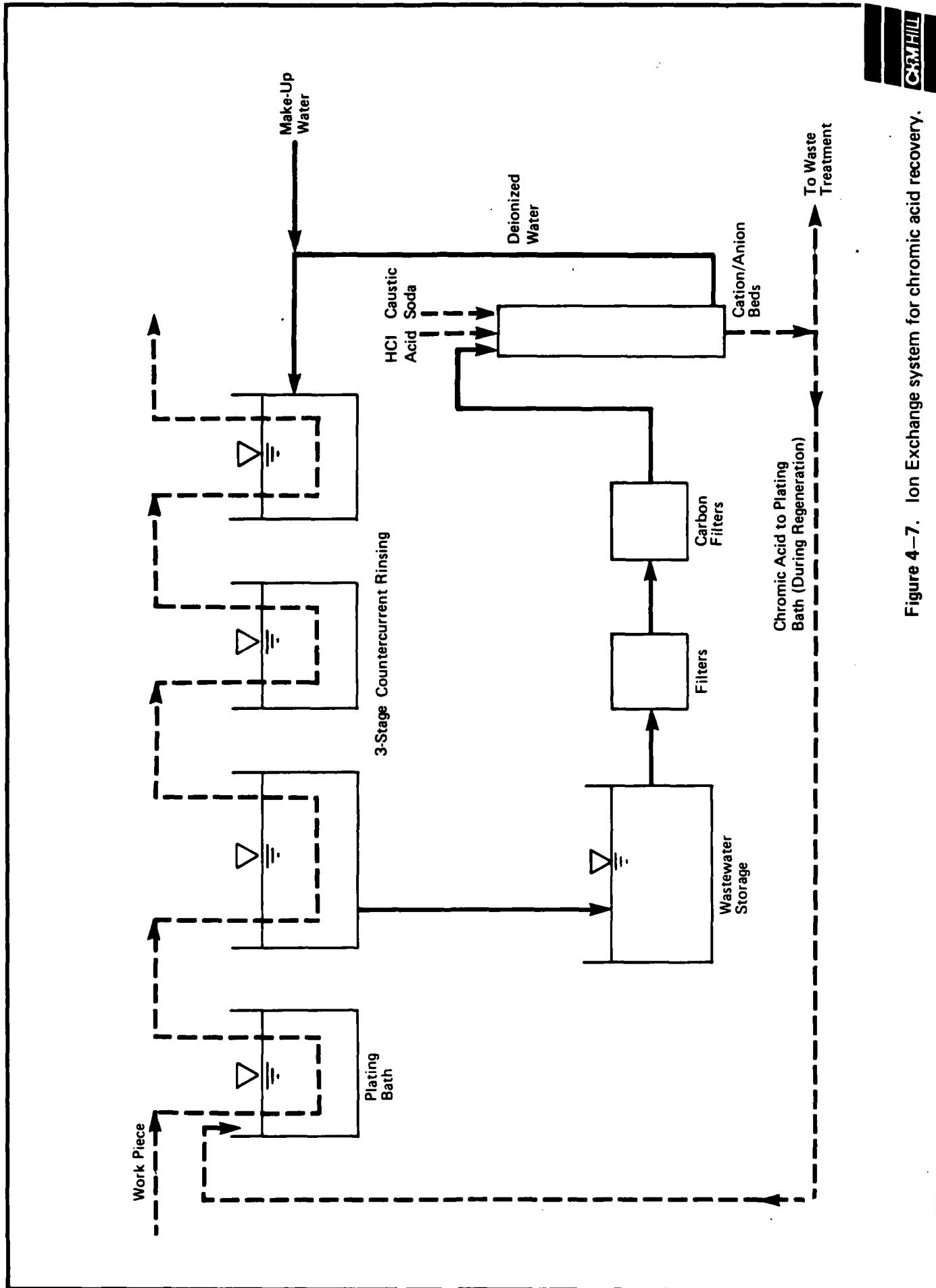


Figure 4-7. Ion Exchange system for chromic acid recovery.

charge of ions displaced from the resin, hence the name ion exchange. Exchanged rinsewater is normally recycled.

Following saturation of the exchange sites, ion exchange resins are usually regenerated by passing acid or base through them, producing a concentrated solution that can be recycled.

In metal plating operations, anionic exchange resins have been used to recover chromic acid from rinsewaters, typically exchanging hydroxide ions for the negatively charged chromic acid anions (Figure 4-7). Anionic resins have also been used to recover cyanide and metal cyanide complexes. Cationic exchange resins have been used to recover metal cations. An IE system typically consists of a wastewater storage tank, prefilters, cation or anion exchanger vessels, and caustic or acid regeneration equipment.

In general, IE systems are suitable for chemical recovery applications where the rinsewater has a relatively dilute concentration of plating chemicals and a relatively low degree of concentration is required for recycle of the concentrate. The recovery of plating chemicals from acid-copper, acid-zinc, nickel, tin, cobalt, and chromium plating baths has been commercially demonstrated. The process has also been used to recover spent acid cleaning solutions and to purify plating solutions for longer service life.

An EPA study estimated that an IE system being operated 5,000 hours per year would cost \$31,000 to install and \$6,000 per year to operate (1979 dollars), resulting in a 5.2 year payback period (12). However, another EPA study estimated that the capital and operating costs (4,000 hours per year) of an IE system would be \$23,000 and \$34,000, respectively (1980 dollars). The significant operating cost difference was due to significantly different assumptions for regeneration frequency and resin life.

Ion exchange recovery systems are not cost effective when drag-out rates are low. According to an EPA study, a favorable payback period of 2.8 years was estimated for chromic acid recovery from rinsewater where the chromic acid drag-out rate is 3 lb/hr (17). For drag-out rates significantly lower (e.g., those used in hard chrome plating), an ion exchange recovery system is not normally cost effective. IE may also be uneconomical where wastewater treatment and sludge disposal costs are minimal.

A reciprocating flow ion exchanger (RFIE) is the most widely used IE system for the recovery of chemicals from plating rinses. These proprietary skid-mounted units are specially

About 20 RO systems have been installed for the recovery of copper sulfate, copper cyanide, zinc sulfate, brass cyanide, and hexavalent chromium. RO use for these baths is limited since RO membranes are attacked by solutions with a high oxidation potential (e.g., chromic acid) or extremes of pH (less than 2.5 or greater than 11). The use of RO for non-nickel baths is expected to increase in the future due to the expected development of membranes which can withstand corrosive and oxidizing environments.

RO use is limited to a moderate degree of concentration. For this reason, it is often coupled with a small evaporator when used to concentrate rinsewaters from ambient temperature baths, such as copper and zinc sulfate. An EPA study evaluated the use of RO and evaporation for the recovery of zinc cyanide from rinsewaters (15). To reach an adequate concentration for reuse in the ambient temperature plating bath, an evaporator was required to supplement the RO system. Capital costs for the RO system and evaporator were \$25,000 and \$40,000, respectively, for a total cost of \$65,000 (1981 dollars). Operating cost of the complete system was \$12,000/year. A \$10,000 savings per year in wastewater treatment, water, and makeup chemical costs was insufficient to offset operating and capital recovery costs.

Another EPA study (16) demonstrated that reverse osmosis was effective in recovering copper cyanide from rinsewater for recycling in a plating bath. However, due to low rinsewater concentrations, short membrane lives, and low wastewater disposal costs, this process was found not to be cost effective.

In summary, reverse osmosis has been shown to be cost effective in concentrating nickel in rinsewaters for reuse in nickel plating baths. However, for ambient temperature plating baths, RO must be supplemented with expensive evaporators in order to concentrate the metals in rinsewater to plating bath strength. The cost effectiveness of an RO metal recovery system depends upon production rate, type and concentration of constituents in the rinsewater, fresh water supply and wastewater disposal costs, and expected useful life of the RO membrane used. Process and operating uncertainties associated with membrane processes that can significantly affect their cost effectiveness include problems with membrane fouling, bath chemical balance, wastewater generation, and operation and maintenance requirements.

Ion Exchange

Ion exchange (IE) utilizes charged sites on a solid matrix (resin) to selectively remove either positively charged ions (cations) or negatively charged ions (anions) from solution. Ions removed from solution are replaced by an equivalent

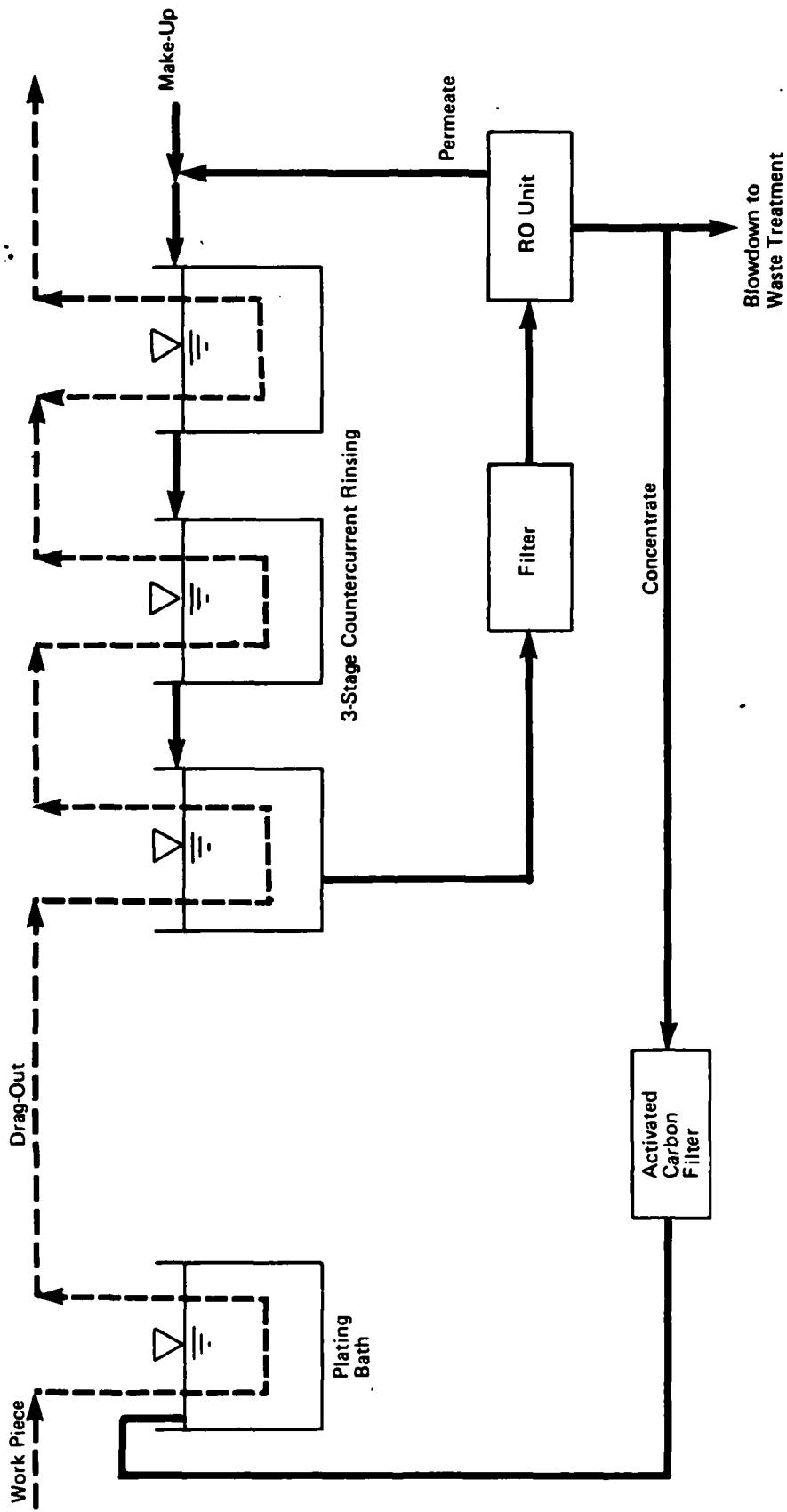
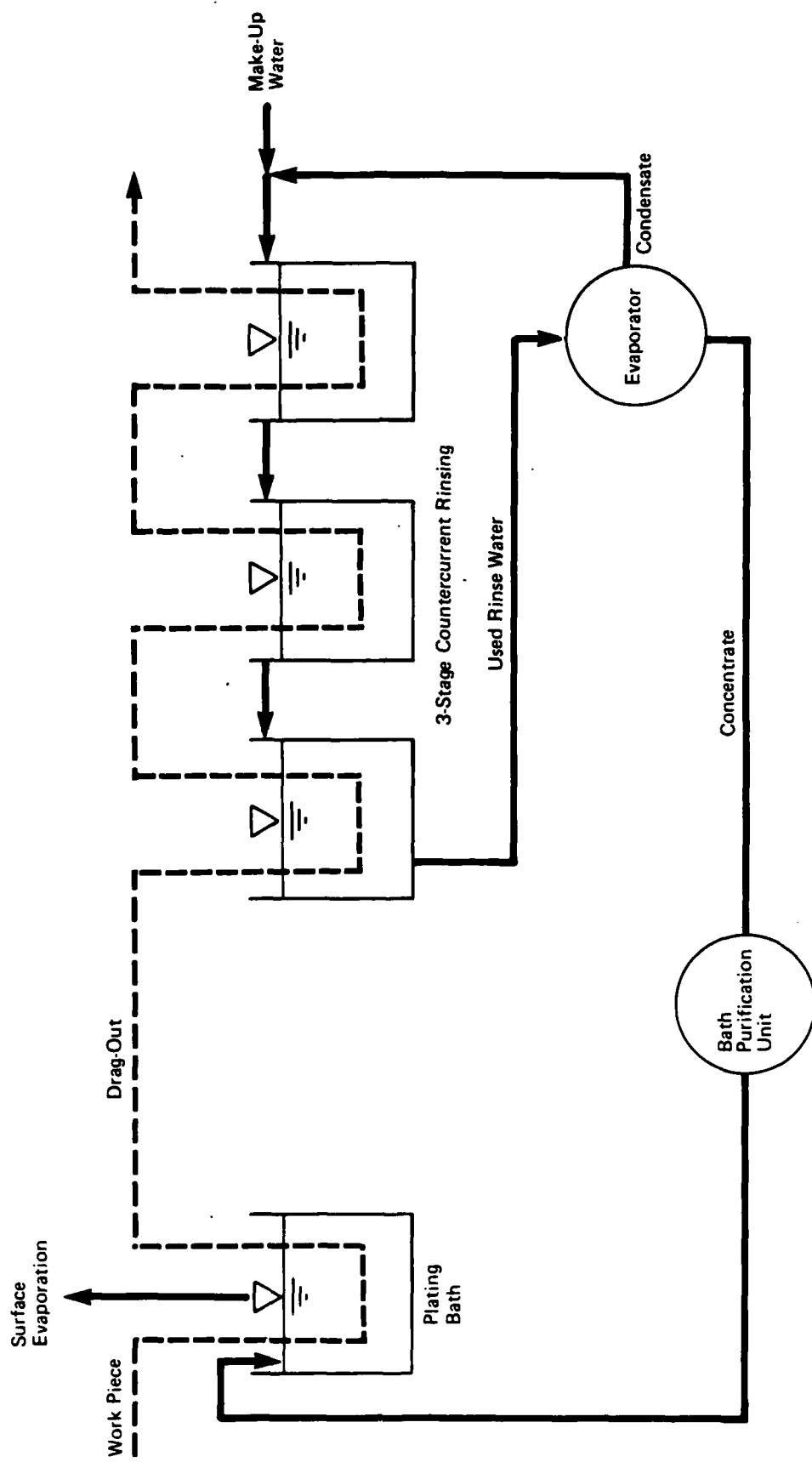


Figure 4-6. Zero discharge reverse osmosis system.

Figure 4-5. Zero discharge evaporation system.



from the plating bath (Figure 4-5). Divalent metal impurities such as iron and trivalent chromium need to be removed from chromium plating baths. Nickel baths are usually purified by activated carbon adsorption. Carbonates, the principal impurities in cyanide baths, are normally removed by chemical precipitation (11). Suspended solids are removed by cartridge filtration.

The degree of concentration required of the evaporator can be reduced by increasing the evaporation rate from plating baths. Increasing the operating temperature can significantly increase the evaporation rate, but only at the expense of increased heating costs. Use of air agitation in a plating tank can also increase the surface evaporation rate. Evaporation can be increased by removing mist suppression "ping-pong" balls from plating tanks; however, this modification would also increase the loss of metals.

Reverse Osmosis

Reverse osmosis (RO) is a demineralization process in which water is separated from dissolved metal salts by forcing the water through a semipermeable membrane at high pressures (400 to 800 psig). The basic components of a RO unit are the membrane, a membrane support structure, a containing vessel, and a high-pressure pump. A typical RO recovery process is shown in Figure 4-6. Rinsewaters must be filtered to prevent fouling of the membranes by solid particles. Reverse osmosis units can concentrate most divalent metals (e.g., Ni, Cu, Cd, Zn) from rinsewaters to a 10-20 percent solution. The concentrated solution is fed back to the plating bath to make up for plating and drag-out losses. Activated carbon adsorption is commonly used to remove organic contaminants. The cleaned rinsewater is then reused.

The capital and annual operating costs for a typical RO plating recovery system were reported to be \$20,000 and \$5,000, respectively (1979 dollars) (12). Due to savings associated with plating chemicals, wastewater treatment, and sludge disposal, the payback period of this process modification was reportedly 4.3 years.

According to an EPA study, the main plating application of RO has been for concentration of rinsewaters from slightly acidic nickel plating baths using cellulose acetate membranes (13). Since 1970, over 150 RO systems have been installed for nickel plating baths. Recovery efficiencies have been reported to be between 90 to 95 percent with membrane lives ranging from 1 to 3 years (14).

Process Modification Description and Experience

Personnel at the North Island NARF have been using IVD of aluminum for about 11 years, having procured one of the first commercially available systems. After many problems with this developmental model, NARF procured a more recent model, which has been greatly improved over the earlier model; however, numerous problems are still experienced in adapting the process to existing plating operations.

Problems developed with the newer IVD system for two principal reasons. First, the equipment was installed in the open plating shop, where considerable contamination of the vacuum chamber by ambient gasses resulted. Second, the IVD system is complicated to operate, with many operating variables needing to be adjusted to produce a good coating; personnel from the plating facility were assigned to operate this complicated technology without adequate skills, training, or incentives.

Since IVD depends on a low concentration of an ionized inert gas to ionize and interact with the aluminum so that it is directed uniformly over the part to be plated, the presence of other gasses in the chamber adversely affects the ability to produce a good quality aluminum deposit. As noted above, the IVD system was located in the open plating shop where contaminating gasses are ubiquitous. Contamination problems have been aggravated by the buildup of aluminum on the inside of the vacuum chamber. Since aluminum adsorbs vapors readily, this aluminum coating adsorbs contaminating gasses from the plating shop, and slowly releases them into the chamber when the vacuum is applied. As the aluminum coating increases, the chamber must be evacuated for progressively longer times to remove these contaminating gasses each time the chamber is opened. To be effectively coated, parts must be kept scrupulously clean. This is not easy to do in an open plating shop.

The IVD system is considerably more complicated to operate than cadmium electroplating or vapor deposition of cadmium. For example, aluminum is vaporized in seven electrical resistance heated "boats." The amperage to each of these boats is controlled separately, and needs to be adjusted as the boats age. As the buildup of aluminum on the inside of the chamber increases, the time required to evacuate the chamber is increased. Eventually, when this time becomes excessive, the aluminum buildup is removed from the chamber.

One problem associated with the process at NARF is that the platers assigned to operate the system did not adequately appreciate the significant differences between IVD and both cadmium electroplating and vacuum deposition of aluminum. Operators familiar with the VacuCad system, which, because it is a line-of-sight process, requires turning of the

parts, were opening the IVD chamber half-way through the deposition cycle to rotate the parts. Not only was this unnecessary, but it also required another long period of evacuation of the chamber before deposition could continue.

Future Direction

Personnel from Materials Engineering at North Island would like to switch completely to IVD of aluminum and thus eliminate the environmental problems associated with cadmium and cyanide. However, current military specifications do not include IVD of aluminum as a replacement for cadmium plating. These specifications would have to be rewritten prior to adoption of IVD.

There is also opposition by production personnel to complete conversion to IVD, since the process is more complex and requires more labor and skill than does cadmium plating. For this reason, parts are being evaluated on an individual basis for conversion to IVD aluminum coating. Most parts are still either electroplated from cadmium cyanide baths or vacuum deposited with cadmium.

The limited use of IVD has aggravated problems with the system at NARF, since extensive use is needed to, as one facilities engineer put it, "work the bugs out of the system." This limited use of the system, and a general lack of cost information by personnel made it impossible to evaluate the economics of the process.

Metal parts that are currently IVD'd with aluminum include landing gears, bolts, and tail hooks. The F-18s, manufactured by McDonnell Douglas, are being produced with all of their steel parts IVD'd with aluminum rather than cadmium plated. For this reason, there is concern on the part of Materials Engineering personnel that the facility will not have solved its problems with the system by the time a significant number of parts need repair on these relatively new fighter aircraft.

In summary, the technology appears to have considerable potential. When the process is performed correctly, the coating has been found to be as protective as cadmium coating. From an environmental standpoint, widespread adoption to replace cadmium plating would eliminate a significant source of hazardous waste. However, unless these systems are made easier to operate and maintain, located in cleaner facilities than plating shops, and supported by skilled and well trained operators, it is unlikely that IVD of aluminum will displace cadmium plating at NARFs.

4.4.2 Non-Cyanide Cadmium Plating at Lockheed-Georgia Industrial Process Description

Air Force Plant 6, located in Marietta, Georgia, is a government-owned, contractor-operated (GOCO) facility operated by Lockheed-Georgia. Employing approximately 15,000 people, the facility has a working floor space of 7 million square feet and occupies 720 acres. The plant was constructed in the 1940s and has been operated by Lockheed since the Korean War.

Lockheed has manufactured all of the Air Force's major cargo planes (C-5s, C-130s, C-140s, and C-141s) at the plant. Approximately 90 to 95 percent of the metal in these cargo planes is aluminum. The remaining 5 to 10 percent is steel, iron, titanium, magnesium, and molybdenum. Parts made from some of these latter materials are plated with cadmium for corrosion protection.

The Lockheed facility utilizes trichloroethylene vapor degreasing, sodium hydroxide alkaline cleaning, and hydrochloric acid pickling to remove grease, oil, dust and rust from parts prior to their being plated. After cleaning, the parts are cadmium plated, baked to remove hydrogen (to prevent embrittlement), immersed in a chromium dip tank, and then painted.

Process Modification Description

In August of 1983, the plating shop switched from an alkaline cyanide cadmium plating bath to an acidic non-cyanide containing cadmium bath. The new plating bath, called "Cadize Plating Solution," is manufactured by Learonel, Inc. This proprietary bath is composed of cadmium oxide, sulfuric acid, two brighteners, one starter, and one stabilizer.

Process Modification Experience

According to Mark Batich, Manufacturing Engineer at Lockheed, modifying the plating process from alkaline cyanide plating to acidic non-cyanide cadmium plating has improved product quality. However, the new process modification is reliable only if it is closely controlled. When the plating bath is idle, the cadmium anodes are left immersed for long periods of time and dissolve into the plating solution. This can result in unacceptably high cadmium concentrations, which in turn result in poor throwing power and dark spots on the finished pieces. When the cadmium concentrations reach unacceptable levels, a portion of the bath is discharged to the industrial wastewater treatment plant.

The process modification has resulted in a small net cost savings. While the new plating solution (approximately \$3.00/gallon) is more expensive than the old cyanide-containing formula, waste disposal costs have decreased. Cyanide-containing wastes are no longer collected in 55-gallon drums and transported offsite for disposal, and chlorine is no longer required for cyanide destruction at the wastewater treatment plant. Labor and maintenance costs, while not quantified, seem to be similar for the two types of plating processes.

4.4.3 Innovative Hard Chromium Plating at Pensacola NARF Industrial Process Description

The Naval Air Rework Facility (NARF) at Pensacola is a government-owned, government-operated (GOGO) facility employing approximately 4,000 people. The primary mission of the facility is to recondition H-3 and H-53 helicopters and A-4 jet aircraft. Reconditioning consists of disassembly of the aircraft and components, paint stripping, removal of dirt, grease, and corrosion products, remanufacture or replacement of parts, reassembly, and application of protective coatings (plating and painting). Worn parts that would be infeasible to replace new are remanufactured by overplating with chromium (hard chrome plating), followed by machining back to original specifications.

The most common electroplating process found at NARFs, Naval Shipyards (NSY), and Naval Air Stations (NAS) is hard chromium plating. Hard chromium plating methods employed at naval facilities have remained essentially unchanged for more than 20 years despite advancements in plating technology and concerns with environmental pollution. Areas on worn parts which do not require a chromium build-up are masked with wax, aluminum foil, lacquer, or tape. After masking, the parts are fastened to racks and suspended in the plating bath. These racks are then secured to the cathode bus bar using C-clamps, providing physical support for the part and completing the electrical circuit. Heavy lead anode bars are then hung from the anode bus bar and positioned around the racked part. Since the lead anodes are 8 feet long and weigh over 50 pounds each, they cannot be easily removed by one man and so are often left sitting in the plating solution when not in use. This results in the anodes slowly becoming passive and ineffective.

After plating, parts must be rinsed to remove plating solution dragged out of the bath on the parts. Continuous flow rinse tanks are usually used to clean plated parts. Rinse flows range from 3 to 12 gpm, resulting in a cost of \$7,000 to \$28,000 per year per rinse tank at Pensacola,

based on 24 hr/d, 260 d/yr operation, a freshwater cost of \$0.34/1000 gal, and a wastewater treatment cost of \$5.81/1000 gal.

Hard chrome plating facilities require large production areas since only one or two large parts can be plated at the same time in a single tank and plating times often exceed 24 hours. The period between receipt of a part at the plating shop and delivery to the machine shop is often a week or more. Since these parts are often critical items to the repair of an aircraft, time for maintenance can be significantly extended by plating delays.

Hard chromium plating is considered the most demanding of all plating processes since it requires close supervision and a high degree of quality control. Most parts require a uniform build-up of chrome so that they can be accurately ground and polished to their required dimensions. Unfortunately, platers using current Navy plating methods have had trouble meeting these specifications or quality requirements. Conventional Navy hard chrome plating often results in uneven plating deposits since the anodes cannot be arranged to provide a uniform current density at the surface of parts. Rejection rates have been as high as 40 percent. Parts which are rejected are stripped and returned for replating, resulting in an increased workload for the plating and machine shops and delays in delivery of the remanufactured part.

Plating baths become contaminated with metal ions leached from parts, plating tanks, racks, and anodes, and conversion of hexavalent to trivalent chromium. These impurities can blemish a plated surface, resulting in a reduction of plating efficiency and quality. Once baths are deemed unsuitable for use, they are bled into the industrial waste system. Due to a buildup of impurities, plating baths at Pensacola have been dumped about every two years. Approximately three times a year, plating baths have been accidentally discharged to the sewer since these plating tanks were not equipped with high level alarms. The cost of treating plating wastewater and replacing the plating solution with new material is high.

Process Modification Description

In response to the difficulties with the current hard chromium plating process, the Naval Civil Engineering Laboratory (NCEL) at Port Hueneme, California adapted an innovative chromium plating system for use at Navy plating shops (29). The "new" plating process uses technology that was developed over 50 years ago in the Cleveland area; hence the term "Cleveland Process" or "Reversible Rack 2 Bus Bar System." Three of the seven plating baths at Pensacola were converted to the Cleveland process by NCEL as a demonstration of this technology. Approximately 50 percent

of hard chrome plating at Pensacola is now performed using this innovative system. Although the plating method varies considerably from conventional procedures, plating efficiencies greatly improved and the resulting end product meets all military specifications.

Modifications from standard Navy hard chromium plating practice were:

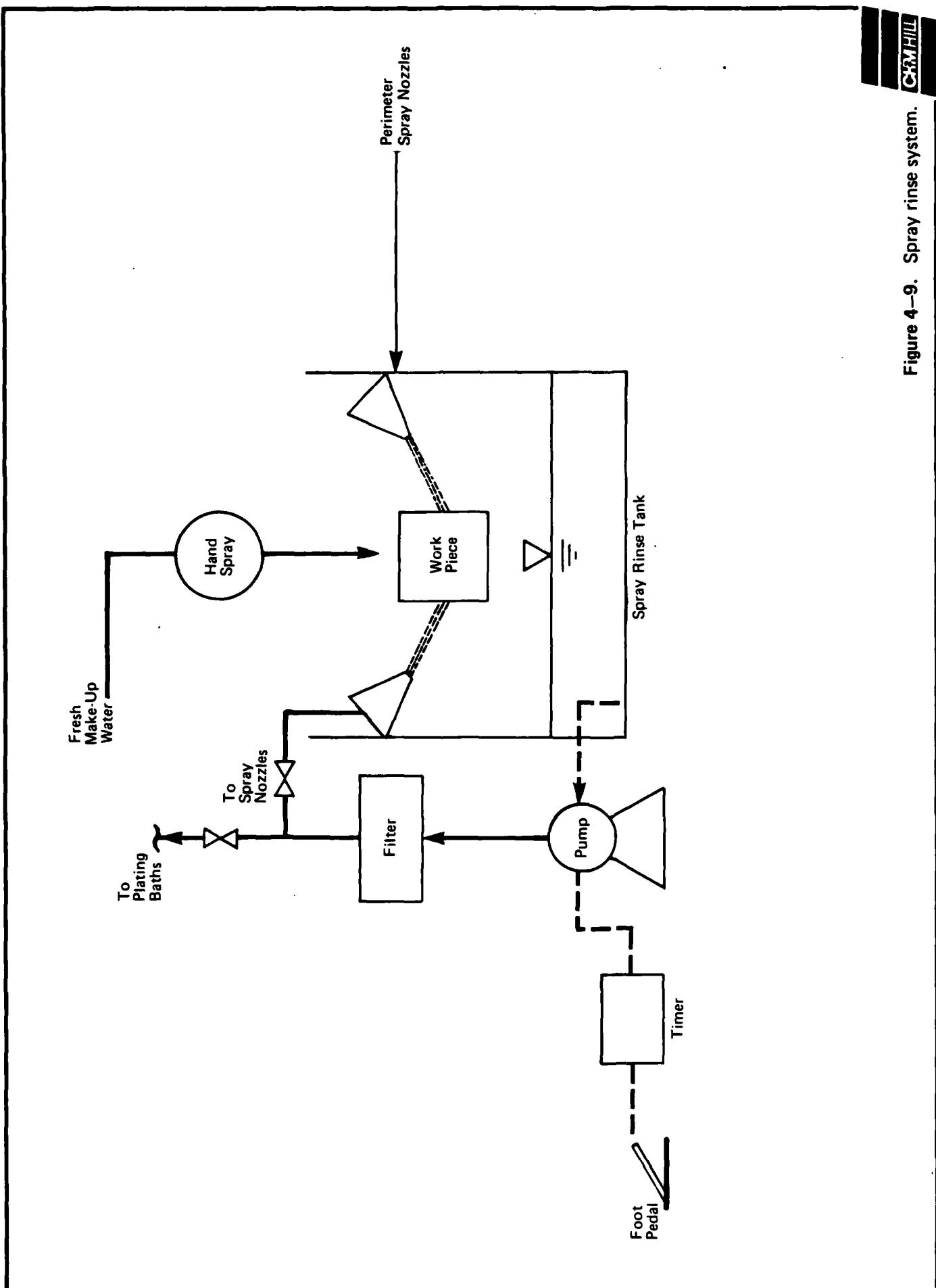
1. Use of conforming anodes and reversible racks to suspend parts instead of the Navy practice of clamping parts on a third cathodic bus bar and using common lead anodes
2. Control by voltage (4.5 volts) rather than by amperage
3. Use of a recirculating spray rinse system (Figure 4-9)
4. Operation at higher temperatures (140°F versus 130°F)
5. Use of a continuous bath purification system to remove contaminating cations from the plating solution (Figure 4-10)

Photographs of the components of this innovative chrome plating system are shown as Figures 4-11 through 4-16 at the end of this discussion.

Use of conforming anodes has produced a more even current density for the Cleveland process, resulting in a more uniform deposit, improved product quality, and an increased plating rate. The reversible racks require considerably less room in the plating tank than the conventional system of clamping anodes and parts to three bus bars. Also, in controlling the process by voltage, rather than by amperage, control of the process is greatly simplified and multiple parts can be plated in the same tank simultaneously.

To assure good adhesion of a new plate to the existing surface, parts are often subjected to a reverse current to etch or roughen the existing surface. The conventional Navy process requires an expensive switching mechanism to reverse polarity of the bus bars for etching; all of the parts in a tank can either be plated or etched at any one time, but both operations cannot be performed concurrently. In contrast, the Cleveland process uses reversible racks that can be picked up and placed in the other direction to reverse current for etching. With this method, some parts in a tank can be plated while others are being etched. As a

Figure 4-9. Spray rinse system.



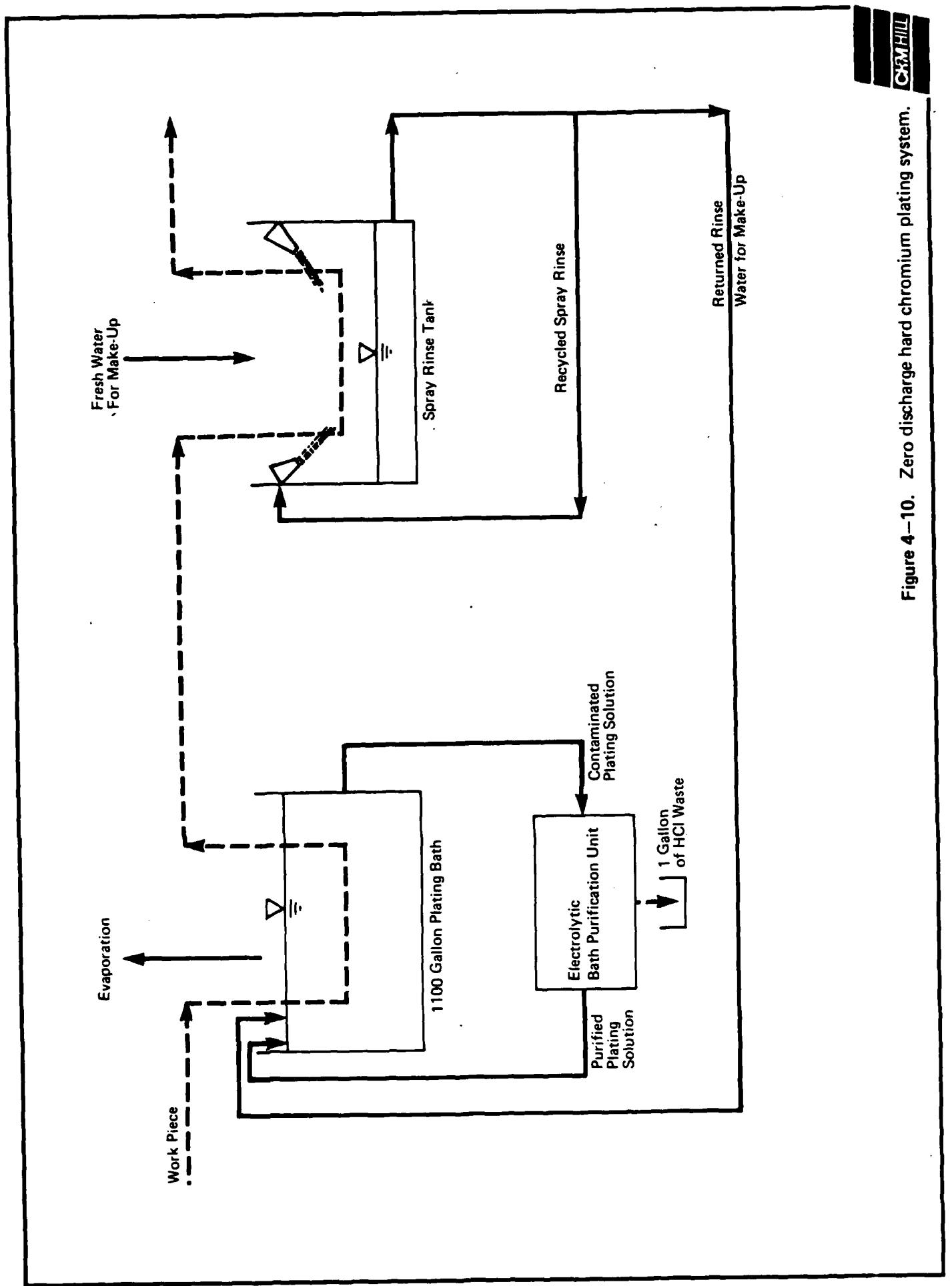


Figure 4-10. Zero discharge hard chromium plating system.

result, 16 to 20 parts of different sizes and shapes could typically be plated simultaneously in one tank, with the Cleveland process, compared to only 6 to 8 in the conventional Navy system.

To reduce the amount of rinsewater used, a prototype spray rinse system was installed in an existing rinse tank. A foot-activated pump recirculates rinsewater through eight high velocity spray nozzles located around the perimeter of the rinse tank. Clean rinsewater is also available via a hand-held sprayer. After repeated use, a portion of the rinsewater is pumped through a cloth filter into the plating tank to replace water lost to evaporation. Operation of the plating bath at a higher temperature has resulted in a higher evaporation rate than in conventional chromium plating as well as an increased plating rate. Because these changes have resulted in a spray rinse system makeup that is less than evaporative losses, the result is a "zero discharge" plating system

Without drag-out to aid in removal of contaminants from the bath, a cleanup process was desirable to reduce the need for plating bath dumps. A "CatNapper-10" treatment system, manufactured by Innova Technology, Inc., of Clearwater, Florida, was installed to continuously remove metal cations from the chromium plating bath. According to the vendor, the "CatNapper" system utilizes a cathode contained within a membrane module to selectively precipitate contaminating metal cations from the plating solution and oxidize trivalent chromium to its hexavalent form. Hexavalent chromium remains on the anode side of the membrane, and is returned to the plating bath. Since impurities are removed from the plating baths, the CatNapper is supposed to extend the life of the bath and reduce the need to increase chrome concentrations or plating voltage. By extending the life of a bath (and thus decreasing the frequency of bath dumps), the CatNapper could indirectly reduce the volume of hazardous waste produced by the plating shop.

Process Modification Experience

Pensacola installed the first demonstration unit, which showed that the Cleveland process could be modified for use at military installations. The Cleveland process is reported to be more "forgiving" than the conventional Navy process. The chromic acid concentration can vary significantly from the standard concentration of 36 oz/gal (e.g., 16 to 40 oz/gal) without a detrimental effect on plating quality.

The conforming anodes in the Cleveland system are attached to the rack and hence are removed with the part, which improves efficiency, and reduces passivation effects, common when conventional anodes are left in the plating tank. Most

conforming anode and rack assemblies (approximately 75 percent) weigh less than 50 pounds and can be handled by a single operator.

Conforming anodes and racks must be fabricated at the facility for each type of part to be plated. First, gridded mats are formed from lead. The mats are then bent to form cylinders. To form large anodes, several cylinders are joined together. Anodes are produced in various diameters and lengths so that they can conform to the size of various parts. The part is then placed inside the anode cylinder and both the anode and the part are attached to the rack. The racks consist of copper cathode bars, aluminum side clamps, and soft steel bolts.

Large parts, such as landing gears, continue to be plated by the conventional process. For large parts, the weight of the total apparatus (rack, conforming anode, and part) would make plating difficult without the use of cranes and so the conventional process is appropriate in these cases. It is also not practical to specially fabricate anodes for unique, large parts which rarely require plating.

Wax is the most commonly used masking material for hard chrome plating. However, since wax melts at 160°F, platers must be careful during plating since bath temperatures of the Cleveland process are kept at 140-145°. To avoid the possibility of melting the wax, many plating shops have switched to masking parts with aluminum foil. They have found that it is generally more economical to install and remove foil, especially if only a small area requires masking. Wax is used on parts which are intricately shaped or have large areas that are not to be chrome plated. Lacquer is sometimes used to mask small parts.

One limitation of the Cleveland process is that it cannot be used for parts chrome plated over a nickel strike. After a part is flash plated with nickel, it must be immediately plated with chromium. With the Cleveland process, too much time is required to remount parts (that have been nickel-plated) to the reversing racks. This represents approximately 15-20 percent of parts that are chrome plated at Pensacola.

NCEL personnel believe that most parts do not require an initial nickel strike. Nickel flash plating is specified for some parts to provide corrosion protection of the underlying basis metal. However, this military specification was written for parts that were originally plated with a decorative chrome layer, in which only a thin deposit (less than 10 millionths of an inch) of chrome covers a part. The specification was inadvertently applied to hard chrome plating. Due to the thickness of chrome plate required on worn parts, the nickel plate provides no

additional protection against corrosion and wear. Gary Whitfield, who is a chemist at Pensacola, and personnel at NCEL have been trying to revise the current military specification so that parts which are hard chrome plated would not require a nickel strike. Laboratory tests are being performed at NCEL to verify that nickel plating is not necessary for parts that are to be hard chrome plated. If they are successful in modifying the specification, all parts could be chrome plated by the Cleveland process.

A partial list of the costs of implementing the Cleveland process at Pensacola is presented in Table 4-3. Costs for manufacturing of racks and conforming anodes, engineering, testing, and training were unavailable.

The process modifications resulted in an initial increase in the average plating rate from 0.002 to 0.004 inch per hour. There was also a significant increase in production because the rack design enabled a significantly greater number of parts to be plated concurrently. As many as 40-50 small parts have been plated in one tank with the Cleveland process. Combining the effects of increased plating speed and plating rack design resulted in a sixfold increase in production.

By the end of 1984, however, the average plating rate had decreased from 0.004 to 0.003 inch per hour. Plating rates became so erratic that platers could no longer predict how long it would take to coat a specific part. Plating personnel expressed the belief that this recent decrease in plating rates was due to build-up of dirt and oxide film on racks, conforming anodes, and tanks. They speculated that a change in bath chemistry may have also contributed to the problem. Charles Carpenter from NCEL expressed his opinion that the reduction in plating rates was due to improper operation and maintenance of the process modifications. He stated that operators often were not maintaining the control voltage at 4.5 volts throughout the plating process. Platers may also have been placing the conforming anodes further than the recommended 2 inches from parts, resulting in a reduction in plating rates.

A high personnel turnover rate at Pensacola has contributed greatly to the problems, because only four platers had been trained on the new system when the process modification was first implemented. These platers attended a week-long course in Cleveland taught by C. Peger of Hard Chrome Plating Consultants Ltd., followed by an additional week of hands-on training at Pensacola. Since this initial training, two of the trained operators have transferred to other departments. Operation and maintenance of the plating

Table 4-3
CAPITAL COSTS, INNOVATIVE CHROMIUM PLATING SYSTEM

<u>Item</u>	<u>Preliminary Estimate</u>	<u>Actual Cost</u>
Convert 3 Plating Tanks		
Equipment, Materials	--	<u>\$5,950</u>
Labor	--	--
Subtotal	<u>\$7,000</u>	<u>\$5,950</u>
Bath Purification System		
CatNapper & Rectifier	--	<u>\$8,900</u>
Misc. Equipment	--	<u>\$1,460</u>
Labor	--	<u>\$1,000</u>
Subtotal	<u>\$8,000</u>	<u>\$11,360</u>
Spray Rinse System		
Equipment	--	<u>\$2,140</u>
Labor	--	<u>\$1,800</u>
Subtotal	<u>\$8,000</u>	<u>\$3,940</u>
TOTAL INSTALLED COST	<u>\$23,000</u>	<u>\$21,250</u>

Note: Dash indicates cost data not available.

shop is made difficult because trained personnel often transfer to higher grade positions in other departments when they become available. The remaining platers have received no formal training and learned about the process modification indirectly from the other platers. In the last year, as many as 50 personnel from three shifts have rotated in and out of the plating shop. Plating personnel seem eager to receive training on the Cleveland process.

NCEL implemented the Cleveland process at Pensacola as a demonstration of the technology. At that time, NCEL did not realize the importance of training all personnel involved with hard chrome plating. Since the prototype installation, NCEL has installed the Cleveland process in three other Navy plating shops. Personnel at the other facilities have received in-depth training on the Cleveland process. In response to the problems encountered at Pensacola, NCEL has budgeted additional funds to train Pensacola platers in the summer of 1985. It is believed that this additional training and subsequent proper operation and maintenance of the Cleveland process will result in an improvement in production and product quality.

The recirculating spray rinse system and bath purification unit have not been properly maintained because some personnel consider the equipment to be a temporary prototype system. The reversible racks and conforming anodes have been better accepted and consequently have been better maintained. About 4-6 hours per week are spent repairing and remanufacturing anodes and racks.

The compositions of plating baths are monitored by a chemist and a technician at the NARF. Once a week, samples are analyzed to determine the chromic acid and sulfate concentrations. The baths are maintained at a chromic acid to sulfate ratio of 80-90 to 1. Problems develop when this ratio exceeds 100-110 to 1. Once every 3 weeks, the baths are analyzed for trivalent chromium concentrations. The chemist controls all chemical additions to the plating baths.

Facilities Engineering at Pensacola reported that they considered the spray rinse system an improvement over the previous countercurrent rinse system. During the initial 4-month test period (March-June 1984), water use was reduced from 350,000 gallons per month per bath for countercurrent rinsing to about 1,200 gallons per month of freshwater used for spray rinsing. Since this was less than the evaporation rate from the plating bath, all of the spray rinewater was used for plating bath makeup, resulting in "zero discharge."

Not convinced that the spray rinse was adequately removing drag-out from parts, platers recently installed a dead rinse tank (i.e., no inflow or outflow) to the chromium plating line for use after a part is rinsed in the spray tank. Although NCEL personnel showed that the spray rinse system was effective in removing drag-out, the platers remained reluctant to eliminate this dead rinse tank. Some platers do not bother to rinse parts with the recirculating spray rinewater but instead use fresh water from the hand-held spray gun and the dead rinse tank for cleaning.

The contents of the dead rinse tank (approximately 500 gallons) are dumped to the industrial sewer once a week. An additional 10,000 gallons per month of fresh water is currently being discharged to the sewer due to a leak in the freshwater spray rinse gun. Because of these deviations from proper operation, the goal of zero discharge is no longer being achieved by the innovative chromium plating system. By reverting to cleaning parts exclusively with the spray rinse system and properly maintaining the rinse equipment, zero discharge could again be achieved.

The spray rinse system has produced total savings of approximately \$25,000 per year per bath, principally due to reduced industrial wastewater treatment costs. Of this savings, \$128 per year is attributable to recovering 108.7 pounds of chromic acid.

The CatNapper system was found to be ineffective in removing impurities from the chromium plating bath during an initial trial run. The system was plagued by failure of the teflon membrane modules, caused by a change of material by a supplier. The membranes were reconditioned and placed back into service. NCEL plans to replace the membranes in the summer of 1985 because they believe the membranes are not functioning properly. NCEL planned further testing of the CatNapper system during March 1985, but these tests were canceled due to failure of the recirculating pump. NCEL estimated that it would take 2 to 3 months for the pump to be replaced. Until then, the CatNapper is scheduled to be out of service. NCEL plans to perform additional testing once the CatNapper is put back in service, to determine the metal impurity removal rate. NCEL also plans to investigate the limits of contamination that can be tolerated in a hard chrome plating bath before plating quality becomes unacceptable.

The manufacturer recommended that the ten membrane modules be cleaned once a week and stated that the cation precipitates could be easily scraped off the membranes or dissolved in hydrochloric acid (17 percent solution). NCEL found that it was difficult to physically scrape the impurities from the membranes; therefore, the membrane modules have been removed from the unit and cleaned by immersion in 1 to 2 gallons of hydrochloric acid.

Future Direction and Other Information

The plating shop at Pensacola NARF is scheduled to be completely renovated to improve both production and safety. It is anticipated that permanent spray rinse systems and bath purification units will be installed in the new hard chromium plating lines. An undetermined number of the remaining four hard chrome plating tanks will be converted from the existing conventional process to the Cleveland process.

Following the successful demonstration of the prototype test installation at Pensacola NARF, NCEL has installed the Cleveland hard chrome process at Louisville Naval Ordnance Center, Puget Sound NARF, and Pearl Harbor Naval Shipyard. The system was also installed at the Cherry Point NARF without NCEL's financial or technical assistance. There are plans to have the innovative plating system installed in all 16 of the Navy's hard chrome plating shops by 1988, and approximately \$1.5 million has been allocated for that purpose. Army personnel attended a 2-day training session at Pensacola NARF in February of 1985 to learn the principles of the Cleveland plating process. The Army now plans to install the innovative plating process in three of its hard chrome shops.

armored vehicles. Approximately 700 tanks are reconditioned at the facility each year.

Reconditioning consists of complete disassembly of tanks and dismantling of their components. Paint, rust, and dirt are removed from components prior to remanufacturing. Paint is removed by sand blasting or stripped using organic solvents or alkaline strippers. Greases and oils are removed using solvent vapor degreasers, followed by alkaline cleaners. Rust and oxide films are removed by sand blasting and acid pickling.

Worn parts that would be infeasible to replace with new parts are reconditioned by overplating with chromium (hard chrome plating) followed by machining back to original specifications.

Process Modification Description

The existing plating facility is approximately 3 years old and is very clean, well organized, and well managed. Many waste reduction features were considered in the design of the facility. The new plating shop is equipped to perform cadmium, chromium, and nickel plating, phosphating, and anodizing. Because of the variety of sizes and shapes of the parts being plated, no records are kept concerning the number of parts or the total surface area plated annually. The plating shop foreman estimated that two to four tons of metal are plated daily. The shop is operated with a full crew for one shift and a skeleton crew for two shifts.

Baths are carefully maintained and the need for bath dumps is almost totally eliminated. When the old plating shop was closed, baths were transferred to the new facility. It was claimed by the plating shop foreman that, in 27 years of operation, only one bath had been dumped, and that was only because contamination resulted from installation of an improper liner in a tank. Bath dumping has been eliminated by careful precleaning and waxing of parts and routine monitoring of tank baths to ensure that they meet specifications. Chromium and cadmium baths are checked weekly. Other baths are checked either monthly or quarterly.

Central filtration systems for each of the different bath chemistries are located in the basement of the plating shop. These systems consist of storage tanks, pumps, and Serfilco cartridge filters. Most baths are filtered 2 to 3 times per week. The filtration system for chromium baths is used infrequently, due to careful pre-cleaning and waxing of parts and the inherently low loading rate on the hard chrome tanks.

Table 4-6
RELATIVE COSTS OF USING LICON CATION EXCHANGE
FOR CHROMIUM RECOVERY FROM RINSEWATER

<u>Cost Type</u>	<u>Description</u>	<u>Without LICON</u>	<u>With LICON</u>
<u>Capital Costs</u>		(\$ Invested)	
Equipment	Cation Exchange Unit Support Equipment	\$0 \$0	\$5,600 \$2,100
Installation	Labor	<u>\$0</u>	<u>\$1,000</u>
TOTAL CAPITAL COST		\$0	\$8,700
<u>Annual Costs</u>		(\$/Year)	
Materials	Plating Chemicals (Makeup) Deionized Water (Makeup) Cation Regen. Chemicals Chemical Destruction	\$ 770 \$ 840 \$ 0 \$ 560	\$ 0 \$ 0 \$ 170 \$ 60
Energy	Electricity	\$ 0	\$ 200
O&M Labor	Operation and Maintenance	\$ 0	\$1,000
Disposal	Sludge Disposal	\$1,800	\$ 120
Capital Recovery Costs (5 Years, 10%)		<u>\$ 0</u>	<u>\$2,295</u>
RELATIVE ANNUAL COSTS		\$3,970	\$3,845

Conclusions

The LICON unit is complicated, requires close supervision, and requires frequent and expensive maintenance. Its use at Naval installations or other facilities with plating shops similar to those at both Charleston and Pensacola is not recommended due to low drag-out rates which reduce the amount of available chromium in the rinsewater, and the availability of more cost-effective and dependable methods to recycle rinsewater and clean up plating solutions.

4.4.5 Plating System at Anniston Army Depot

Industrial Process Description

Anniston Army Depot, constructed in 1941, is a government-owned, government-operated (GOGO) industrial facility, employing approximately 4,500 people. The principal mission of the facility is to recondition used tanks and other

Table 4-6 details the costs of recycling rinsewater using cation exchange polishing in comparison with the costs of chemical make-up, treatment, and disposal of the rinsewater. Recycling of rinsewater with cation exchange polishing was found to have a payback period of approximately 5 years.

The report claimed that additional savings could be realized if the cation exchange were used at facilities where plating baths are dumped frequently. It should be noted that cation exchange is not feasible for cleanup of concentrated chromium baths, and use on recycled rinsewater only removes those cationic contaminants that are removed by drag-out that would be removed with the rinsewater if it were not recycled.

Mixed Rinse Concentration For Disposal

In addition to the testing of the LICON unit for recovery of chromium from rinsewater, the vapor recompression unit was evaluated for its effectiveness at concentrating a mixture of chromium-containing rinsewaters to reduce the volume that had to be disposed of. Rinsewaters tested were from passivation, anodic stripping, chrome and nickel stripping, copper stripping, chromate conversion, and electropolishing. The vapor recompression evaporator concentrated these rinsewaters to approximately 10 percent dissolved solids. Problems encountered during the test included scaling of heat transfer surfaces and precipitation of solids in the concentration tank; these are problems that, if left unresolved, could potentially render the process totally ineffective.

Recently promulgated RCRA amendments severely limit the disposal of liquid hazardous wastes. Vapor recompression evaporation does not produce a solid waste, and the volume of solidified waste from further treatment of this concentrate would not be significantly less than that produced by conventional treatment. This experiment was an attempt to find a use for the LICON unit, rather than an evaluation of its widespread applicability.

Use of the LICON Unit for Chromium Plating Bath Cleanup

The feasibility of using the LICON unit to clean up contaminated chromium plating solutions was evaluated. Waste plating solutions were first diluted with water to protect the ion exchange resins, cations were then removed in the cation exchange cleanup module, and the solutions were then concentrated to bath strength in the vapor recompression module. These reconstituted baths successfully passed plating tests.

Table 4-5
RELATIVE COSTS OF LICON UNIT FOR CHROMIUM RECOVERY

<u>Cost Type</u>	<u>Description</u>	<u>Without LICON</u>	<u>With LICON</u>
<u>Capital Costs</u>		(\$ Invested)	
Equipment	LICON System	\$0	\$65,800
	Building	\$0	\$ 3,700
	Extra Tank	\$0	\$ 3,100
Installation	Building (3MD \$200)	\$0	\$ 600
	Installation (10MD \$200)	\$0	<u>\$ 2,000</u>
TOTAL CAPITAL COST		\$0	\$75,200
<u>Annual Costs</u>		(\$/Year)	
Materials	Chromic Acid ¹	\$ 770	\$ 0
	Deionized Water ¹	\$ 840	\$ 230
	Cation Regen. Chemicals	\$ 0	\$ 60
	Contaminated DI Water	\$ 560	\$ 117
	Treat		
	Maintenance Supplies	\$ 0	\$ 600
Energy	Electricity	\$ 0	\$ 4,200
O&M	Operation (888 MH \$8.00)	\$ 0	\$ 7,100
Labor	Maintenance (525 MH \$8.00)	\$ 0	\$ 4,200
Disposal	Sludge Disposal	\$1,800	\$ 120
Capital Recovery Costs (5 Years, 10%)		<u>\$0</u>	<u>\$19,838</u>
RELATIVE ANNUAL COSTS		\$3,970	\$36,465

¹Without LICON, for plating bath makeup; with LICON, for cooling compressor.

its low pH. Additional problems were caused by failure of seals in the concentrated chromic acid pump. These problems were solved by replacement of the pump seals and installation of new teflon gaskets.

After problems that resulted in contamination of the concentrated plating solution had been resolved, the concentrate from the evaporator was found to be acceptable for reuse in the plating tanks.

Operation and maintenance (O&M) of the LICON unit for evaporative recovery required approximately 2 hours per shift, or approximately 6 hours per day. This amounted to approximately 1,400 manhours per year. The mean time between failure (MTBF) was determined to be approximately 40 hours. It should be noted that as the major problems already mentioned were resolved, the O&M effort decreased and the MTBF increased. Regardless, it can be concluded that operation and maintenance of the LICON unit is labor- and capital-intensive.

Table 4-5 is a comparison between the cost of utilizing the LICON unit for evaporative chromium recovery and the cost of operating the chromium plating system without chromium recovery. This comparison includes only those costs that are affected by the process modification, and does not include the total cost of either operation.

This analysis shows that use of the LICON unit for chromium recovery from hard chromium plating rinsewater is not cost effective, as it results in a net cost of approximately \$30,000 per year more than the existing operation. Moreover, by using flow control and maintaining the recommended maximum contaminant level in the rinse system, the Charleston facility has been able to reduce rinsewater flows to below that required to make up for evaporation.

Rinsewater Cleanup Using Cation Exchange

Since flow control was used to reduce the rinsewater flow to that required to make up for evaporation in the plating tanks, the feasibility of recovering the chromium in the unconcentrated rinsewater by direct addition to the plating tanks was investigated. Since this closed cycle operation could result in a buildup of contaminants, the effectiveness of using the LICON cation exchange unit to remove cationic contamination from the rinsewater prior to reuse was evaluated.

To further reduce the flow of rinsewater required, the cation exchanged rinsewater was used in spray rinse nozzles located above each plating tank. The recycled rinsewater was found to be contaminated by sulfate, an anion, due to platers rinsing parts from an etching tank in the chrome rinse system. Since this practice was discontinued, the system has been working effectively.

2. Cleanup of Rinsewater by Cation Exchange--use of the cation exchange unit for removing cationic contaminants from the rinsewater, which was then used for evaporation makeup and spray rinsing into the hard chromium plating tanks.
3. Mixed Rinse Treatment by Evaporation for Disposal--use of the evaporator for concentrating the metals from several other plating bath rinses as an alternative to conventional treatment for disposal.

The results of the evaluation of the LICON unit and associated parts are discussed below, along with a summary of the LICON unit's use in cleaning up concentrated plating solutions. It should be noted that although a recycle and reuse system was developed that essentially eliminated the need to concentrate the chromium plating rinsewater, personnel at Charleston continued to evaluate this function of the LICON unit in the interest of giving it a fair trial.

Evaporative Recovery

Major problems were encountered during operation of the LICON vapor recompression concentrator. First, use of the condensate for cooling of the compressor lobes had to be discontinued due to severe corrosion of the ductile iron compressor caused by the acidity of the distillate (pH 4.7-6.0). Chemical analysis of the condensate showed a high concentration of carbonic acid, but no carryover of chromic acid. The carbonic acid was thought to be caused by a breakdown of alkalinity in the concentrate and subsequent formation of carbonic acid in the condensate. Corrosion of the compressor resulted in iron contamination of the condensate. Since use of this condensate to cool and seal the lobes of the vapor recompressor resulted in corrosion of the compressor, deionized (DI) water from the shop was used in its place. Approximately 20 gal/hour of shop DI water was used for this purpose. The unit produced approximately 30 gal/hour of contaminated condensate, resulting in the unit becoming a net consumer of distilled water.

Possible solutions to the corrosion problems would be to use a more expensive vacuum pump made of corrosion-resistant alloys or to use a non-sealed compressor.

The second problem attributable to the aggressive nature of the condensate water was corrosion of the cast iron distillate pump, further contaminating the condensate. Replacement of this pump with one made of stainless steel reduced iron contamination of the condensate. Nevertheless, the produced water was unsuitable for use and had to be treated in the industrial wastewater treatment plant due to

4. The compressor seals deteriorated rapidly, and the unit failed to pull its rated vacuum. This severely limited the energy efficiency of the process. Corrosion products from pump deterioration contributed further to contamination of the condensate water.

In summary, operation of the LICON unit at Pensacola was uneconomical, costing approximately \$1,500 per pound of chromium recovered (3). This can be compared with a replacement cost of less than \$2 per pound for new chromium plating solution.

A reliability, availability, and maintainability (RAM) study was performed by Carpenter (3). The reliability and operational availability of the LICON unit was rated as very poor, principally due to problems with the vapor recompression unit. In summary the report stated:

"The LICON vapor recompression unit appears sound in theory, but needs more work before it will be a reliable, viable alternative to consider for use in metal recovery....Economically, the LICON unit is a liability at NARF Pensacola."

The LICON evaporator with the vapor recompression unit and cation exchange module was relocated from Pensacola to Charleston NSY, South Carolina, for further testing and evaluation on the hard chromium plating line at that facility. A new contract for refurbishing and installing this equipment and an additional maintenance agreement were negotiated with LICON. As part of the refurbishment, a new compressor was installed in the evaporator to eliminate the oil seal problem observed at Pensacola.

The feasibility of using the LICON unit for chromium recovery was evaluated over a 9-month period during which information was collected concerning the costs and level of effort required for installation, startup, operation, and maintenance. In addition to recovery of chromium from rinsewater, the LICON unit was also used to clean up contaminated plating baths. The cation exchange module was tested by itself to remove cations from rinsewater for plating bath makeup. In addition, the vapor recompression evaporator was used to concentrate mixed plating wastes and thus reduce their disposal costs.

The LICON unit's performance at Charleston was evaluated by Baker S. Mordecai (30). The report evaluated the feasibility of using the LICON unit for three separate tasks:

1. Evaporative Recovery--use of the vapor recompression evaporator and cation exchange unit for hexavalent chromium recovery.

of 35,000 pounds of chromium had been projected for the unit at this installation, based on the assumption that the drag-out rates and rinsewater chromium concentrations would be the same as those of commercial decorative chrome platers.

During the year and a half of operation at Pensacola NARF, the LICON unit each day cost approximately \$195 to operate, produced 552 gallons of poor quality distilled water, and recovered approximately a half pound of chromium, which was unsuitable for reuse. The initially forecast recovery rate did not take into account the differences between hard chrome plating and decorative plating. Because of the long plating times and low production rates, drag-out to rinsewater is orders of magnitude less for Navy hard chrome plating than for commercial decorative plating. At Pensacola NARF the maximum chromium drag-out available for recovery was measured to be approximately 90 pounds a year.

The LICON unit was plagued by four major problems related to its operation at Pensacola:

1. The condensate water produced by the unit was contaminated by both product and oil, which made it a liability rather than an available resource. The product contamination was due to the use of brighteners and additives to the plating baths, which resulted in foaming in the LICON evaporator unit. This is often a problem with wastewater evaporators. The product-laden foam would travel up the separation column, through the compressor, and into the distillate tank. The oil contamination was due to compressor oil carryover.
2. Since condensate water was unsuitable for use, the vapor recompression unit was a net user of 20 gallons per hour of distilled water for cooling. This cooling water was discharged to the industrial wastewater treatment plant, where it was treated at a cost of \$5.37 per 1,000 gallons.
3. Pumice and wax, which are used in the plating operations, were carried over into the rinsewater feed loop. No provision was made for pumice or wax removal in the LICON unit. While wax carryover was eliminated by installing a filter prior to the ion exchange unit, attempts to isolate pumice from the rinsewater feed were unsuccessful. Pumice was concentrated along with the chromium, making the concentrated chromium solution unacceptable for reuse. (This shows why an initial complete waste characterization and materials balance are always necessary for a process design.)

Table 4-4
CHARLESTON NSY HARD CHROMIUM PLATING OPERATING CONDITIONS

Parameter	Value
Chromic acid concentration	32-40 oz/gal
Chromic acid/sulfate ratio	100:1-125:1
Bath temperature	100-140°F
Aeration rate	8-15 cfm

Note: Anode is insoluble lead
(lead-tin, lead-antimony).

Process Modification Description

A study was initiated to evaluate a method to reduce or eliminate chromium waste discharges from the plating shop by recovery of chromium from rinsewaters. The system tested, an ion exchange/evaporator, manufactured by LICON, Inc., was designed to recover chromium from up to 33 gallons per hour of hard chrome plating rinsewater. The LICON system consisted of two basic modules: a cleanup ion exchange module used to remove cations (principally iron and trivalent chromium) from dilute rinsewater; and an evaporation unit for concentration of the cation-free rinsewater to plating bath strength. The evaporator unit utilized vapor recompression and waste heat recovery to reduce energy consumption. The final product was to be a cleaned rinsewater concentrate of plating bath strength and a condensate of distilled water quality as a beneficial byproduct.

The rinsewater ion exchange module has a receiving tank, from which rinsewater is circulated through a cation exchange bed and back to the storage tank. Cleaned rinsewater is pumped through the condensate heat exchanger to the vapor recompression unit concentrate tank, where it is mixed with previously concentrated chromic acid. This mixture is evaporated under a vacuum, lowering the boiling point to approximately 130°F. Steam is removed from the evaporator through the compressor. Since pressurized steam condenses at an elevated temperature, the heat of condensation can be transferred to the water in the evaporator by a heat exchanger. A portion of the cooled distilled water is used to cool and seal the lobes of the vapor compressor.

Process Modification Experience

The LICON unit was originally tested at the Pensacola NARF. An evaluation of the LICON unit's performance at that facility was prepared by Carpenter (3). An annual savings

4.4.4 LICON Chromium Recovery at Charleston NSY

Industrial Process Description

The NSY at Charleston, South Carolina, is approximately 150 years old and employs approximately 8,000 people. The facility's mission is to repair, refurbish, and recondition naval surface ships and fossil- and nuclear-fueled submarines.

The plating shop at Charleston NSY performs several operations, including hard and flash chromium, cadmium, copper, nickel, and zinc electroplating, silver brush plating, plasma spray and hot dip galvanizing, stripping of chromium, nickel, and copper, application of chromate conversion coatings, phosphating, electropolishing, and passivation.

Hard chromium (or chrome) plating is done to increase the service life of parts or to salvage worn or mismatched parts. Items hard chrome plated at Charleston consist primarily of functional parts such as rotors, hydraulic cylinders, bearing caps, shafts, and end bells from mechanical and electrical machinery on ships.

Parts are hard chrome plated to an average plated thickness of approximately 20 thousandths of an inch, with a range of 1 to 40 thousandths. All parts are overplated and subsequently ground to final dimensions. To achieve the thickness required, parts are plated for an average of 27 hours.

At Charleston, hard chrome plating is performed in 13 plating tanks with a combined surface area of 125 square feet. These plating baths are significantly underutilized. Long plating times and job shop conditions have resulted in low production rates. Usually less than 150 parts have been hard chrome plated each month (12 parts per tank). This low production rate and overcapacity have resulted in extremely low drag-out rates (0.08 gallons of plating bath per hour).

Typical bath composition and operating conditions used at the Charleston plating shop are shown in Table 4-4.

Industrial waste treatment personnel have control of the countercurrent rinsewater inlet valves. Because it is in their best interest to minimize the rinsewater flow going to waste, they maintain the recommended maximum contaminant level in the rinse tanks. This has resulted in a rinsewater flow rate that has been lower than the evaporation rate from the plating baths.

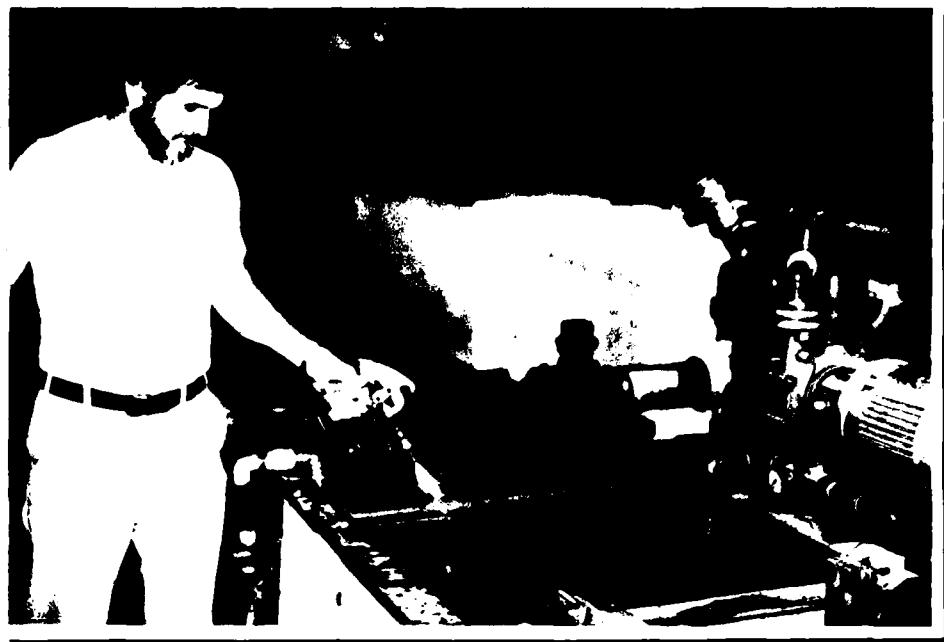


Figure 4-15. Hand spray rinse.

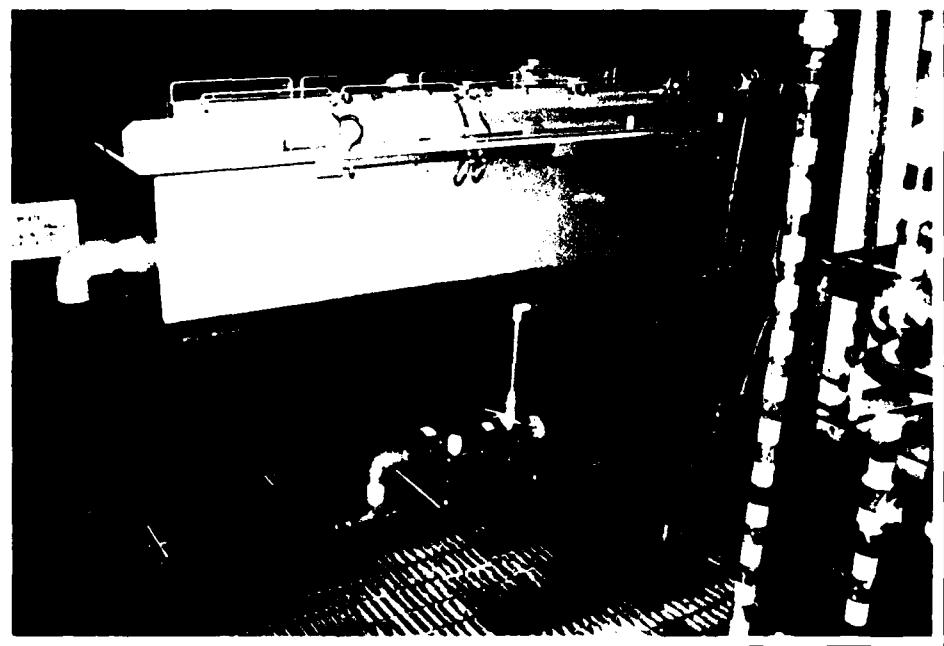


Figure 4-16. "CatNapper 10" electrolytic plating bath purification system.

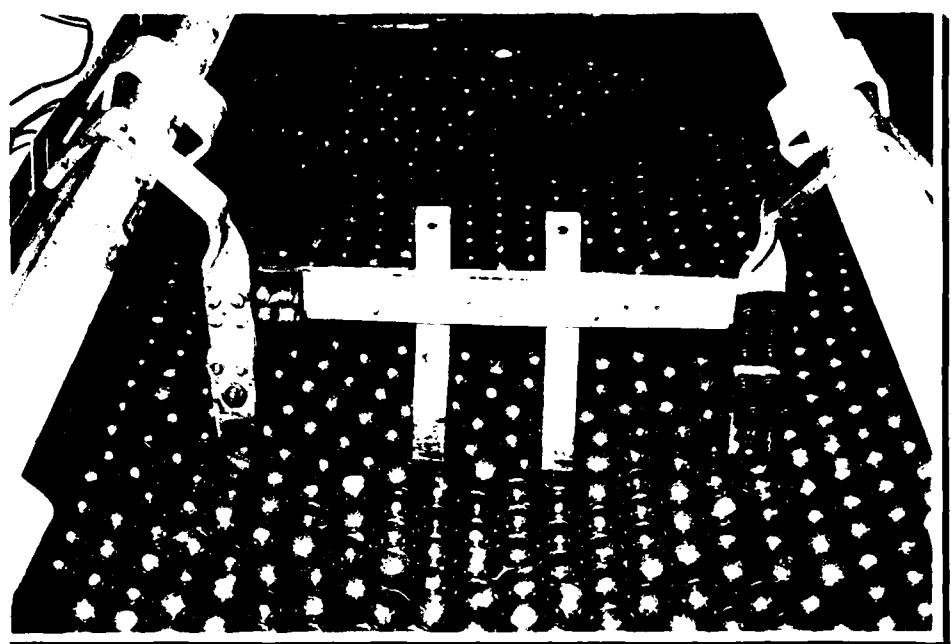


Figure 4-13. Chrome plating bath with 2 bus bars and reversible rack.

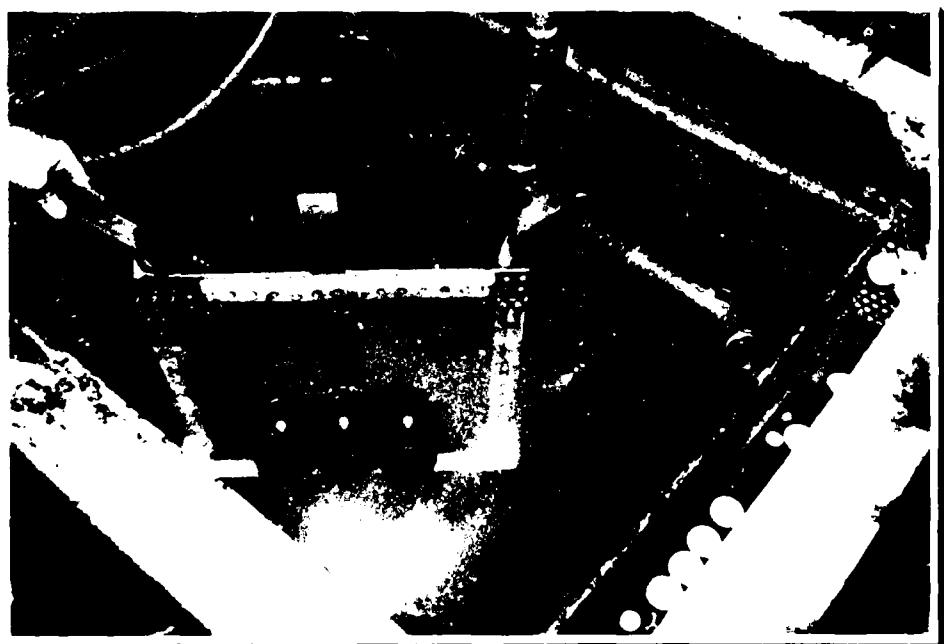


Figure 4-14. Spray rinse of plated part and reversible rack.

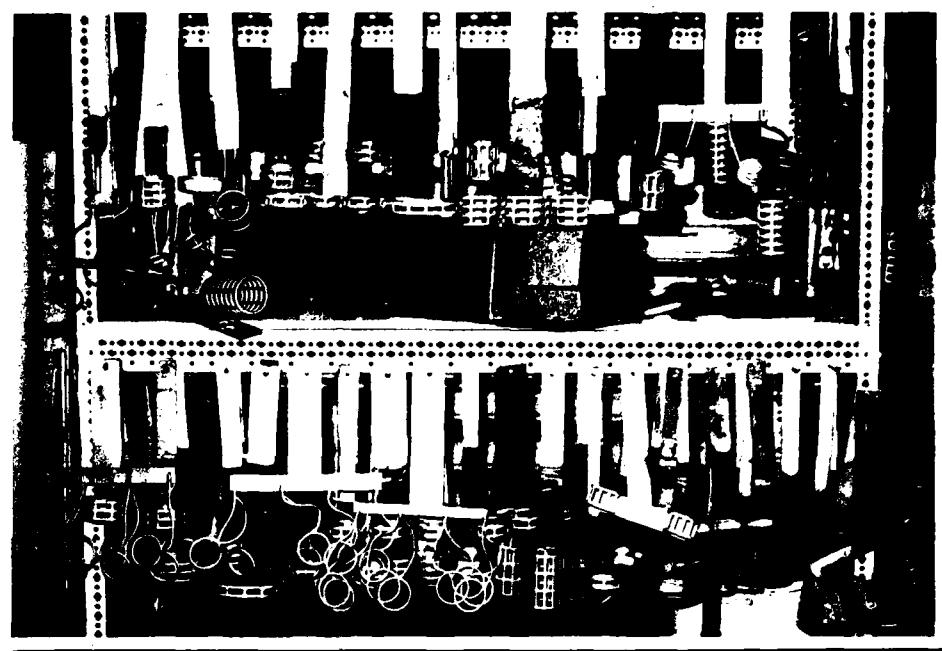


Figure 4-11. Assortment of conforming anodes.

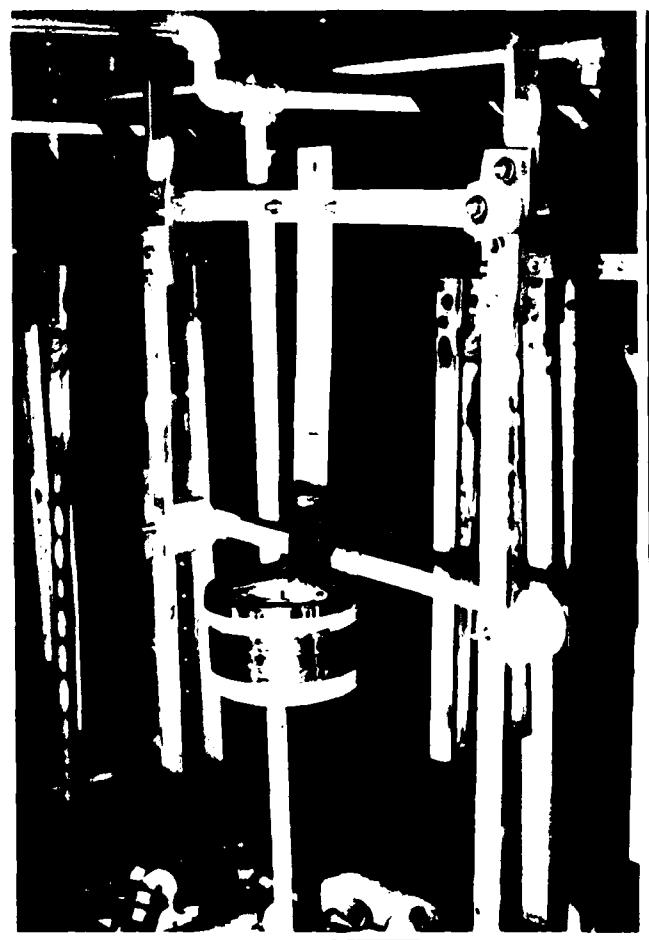


Figure 4-12. Reversible rack with conforming anode.

NCEL has tailored the innovative chrome process to fit the space and operator preferences of each individual facility. NCEL has worked closely with each facility's plating personnel to foster acceptance of the process modification and to minimize disruption of normal operations. For example, the plating foreman at Louisville prefers manual operation and control of plating baths. Therefore, NCEL did not install extensive instrumentation and control (I&C) systems, except for high level alarms on the plating tanks. In contrast, at Puget Sound an elaborate I&C system was installed because personnel there were more receptive to automatic control.

CatNappers were installed at Pearl Harbor and Puget Sound. A unit similar to a CatNapper, manufactured by Pfaulder, was installed at Louisville. This device uses unglazed "clay pots" for the anode membranes and a stainless steel cathode. NCEL is evaluating which manufacturer's equipment is more effective at removing contaminating cations.

Although a continuous bath purification system was not installed at Cherry Point, the plating chemist closely maintains the proper bath composition and periodically removes dissolved solids by precipitation. As a result, baths have only needed to be dumped at 5- to 10-year intervals.

Rinsewater tanks are single flow-through type, with flow rates controlled by conductivity. At other DOD facilities, numerous problems have been encountered in maintaining conductivity control systems, and these controllers are therefore frequently bypassed. The conductivity controllers at the Anniston facility appeared to be in good working condition, with minimal problems encountered in their use.

Countercurrent rinsing was considered for the facility, but was not used because of budget restrictions, and the plating supervisor did not believe that the reduced treatment costs offset the additional construction costs. He had seen the spray rinse system at Pensacola NARF (Section 4.4.3) but was not sufficiently convinced of its advantages to incorporate this system at Anniston.

Hard chrome plating is performed on a line that consists of seven plating tanks and seven rinse tanks, plus assorted tanks for waxing and dewaxing. Parts are plated for 24 to 48 hours. The baths are maintained at 33 ounces of chromium per gallon, with weekly additions to make up for drag-out and plating losses. The reject rate for parts has been only about 2 percent compared to as high as 40 percent at NARFs. Approximately 5 to 6 batches of rinsewater, containing less than 50 mg/L of chromium, are treated each day.

Cadmium is currently being plated from alkaline cyanide baths, using a conventional line and an automated bucket line. Non-cyanide containing baths were considered, but rejected by the plating shop supervisor because he believed that the resulting cadmium plate was not as corrosion-resistant and that non-cyanide cadmium baths had a significantly reduced throwing power. He also noted that he has never had an accident with the cyanide baths.

Wastes are segregated for treatment at Anniston. The alkaline cadmium cyanide rinsewaters are treated for cyanide destruction by alkaline chlorination and cadmium precipitation at an optimum pH prior to mixing with other wastes. Chromium rinsewaters are likewise segregated for separate chromium reduction at low pH (2.5) using metabisulfite and ferrous sulfate followed by alkaline precipitation with other metal-containing wastes.

Chromic acid is used at several locations for cleaning purposes. These cleaning solutions are disposed of approximately once every 5 years.

4.4.6 Sulfide Treatment of Plating Wastewater at Tobyhanna Army Depot

Industrial Process Description

Tobyhanna Army Depot, a government-owned, government-operated facility constructed in 1953, employs approximately

4,300 people to rebuild and repair electronics and communications equipment. Wastewaters containing metals are generated by the metal finishing shop and the printed circuit board fabrication shop. These wastes are treated in an industrial waste pretreatment plant prior to being combined with other wastewaters for treatment in a trickling filter plant and subsequent discharge to a stream. Information used in this report came from reports and literature (31-32), and from a visit to the facility and followup phone conversations.

The metal finishing shop operates as a "job-shop," plating and finishing an assortment of small parts on an as-needed basis, using 32 process and 32 rinse tanks. Processes include copper, nickel, chromium, cadmium, tin, and silver plating, anodizing, etching, phosphating, and immersion coating. Metal finishing is provided principally for corrosion protection and to modify surface electrical properties of the basis metals. No hard chrome plating is performed.

Process Modification Description

Rinsewaters from the plating shop are segregated into three waste streams as follows: those containing cyanide, those containing chromium, and other acid and alkaline wastes. These waste rinsewaters are pumped separately to the pretreatment facility.

Concentrated waste solutions are pumped into drums and disposed of as hazardous waste, rather than being bled to the pretreatment plant. Hydrochloric acid and bright dip solutions are dumped approximately once every 2 weeks. Other solutions are dumped at 6- to 9-month intervals.

Approximately 200 drums of concentrated waste are produced each year by the plating shop, mostly waste alkaline and acid cleaners. Plating baths themselves are rarely dumped, but are tested and maintained by chemical addition.

The printed circuit (PC) board operation manufactures the various PC boards needed for rebuilding and repairing electronics and communications equipment at the depot. Waste produced by the PC board facility is principally rinsewater from plating and etching processes. Rinsewaters contain lead and copper, and are combined with acid and alkaline plating wastes for treatment in the industrial pretreatment plant. Concentrated solutions are drummed for disposal as hazardous waste. Approximately 10 drums of waste are produced each month, and contain mostly waste etching solutions.

The 37-gallon-per-minute (gpm), industrial pretreatment facility was designed and constructed to provide a full-scale demonstration of the soluble sulfide precipitation process for the pretreatment of a metal finishing wastewater. Soluble sulfide precipitation was selected because the lower solubility of metal sulfides was expected to result in better metal removal efficiency than conventional hydroxide precipitation. Metal sulfide sludges were expected to be more easily thickened and dewatered and less easily leached than metal hydroxide sludges.

The three segregated wastes were treated separately. Cyanide-containing wastes were treated in a two-stage alkaline chlorination process for complete cyanide oxidation. Chromium-containing wastes were acidified to pH 2.5 and treated with sodium metabisulfite to reduce hexavalent chromium to the less soluble trivalent form. Following separate treatment, these wastes were combined with the acid/alkali and PC board wastes for treatment by soluble sulfide precipitation.

A flow diagram of the soluble sulfide precipitation treatment plant is shown as Figure 4-17. This treatment system consists of pH adjustment with caustic soda, addition of ferrous sulfate and anionic polymer as coagulants, addition of sodium sulfide to precipitate metals, flocculation, parallel plate clarification, gravity sand filtration, and peroxide destruction of residual sulfide. Sludge processing consists of gravity thickening and dewatering in a plate and frame filter press.

Filter cake is drummed for disposal offsite in a hazardous waste landfill by American Recovery of Baltimore, Maryland. Approximately one drum of dewatered sludge is produced per week. EP toxicity testing resulted in a finding that the sludge was a hazardous waste, principally due to cadmium leachability. Any reduction in leachability due to sulfide precipitation was therefore of no practical benefit, with respect to its hazardous waste classification.

Process Modification Experience

During initial operation, the treatment plant met its design performance standards, with the exception of those for aluminum and lead. The high aluminum concentrations were not considered significant, since the facility does not have an effluent requirement for aluminum. The discharge of lead only temporarily exceeded the limit. Table 4-7 compares the effluent composition with design and permit limitations for a 6-month period (32). During this period, the maximum zinc standard was slightly exceeded, and the maximum suspended solids limit was exceeded.

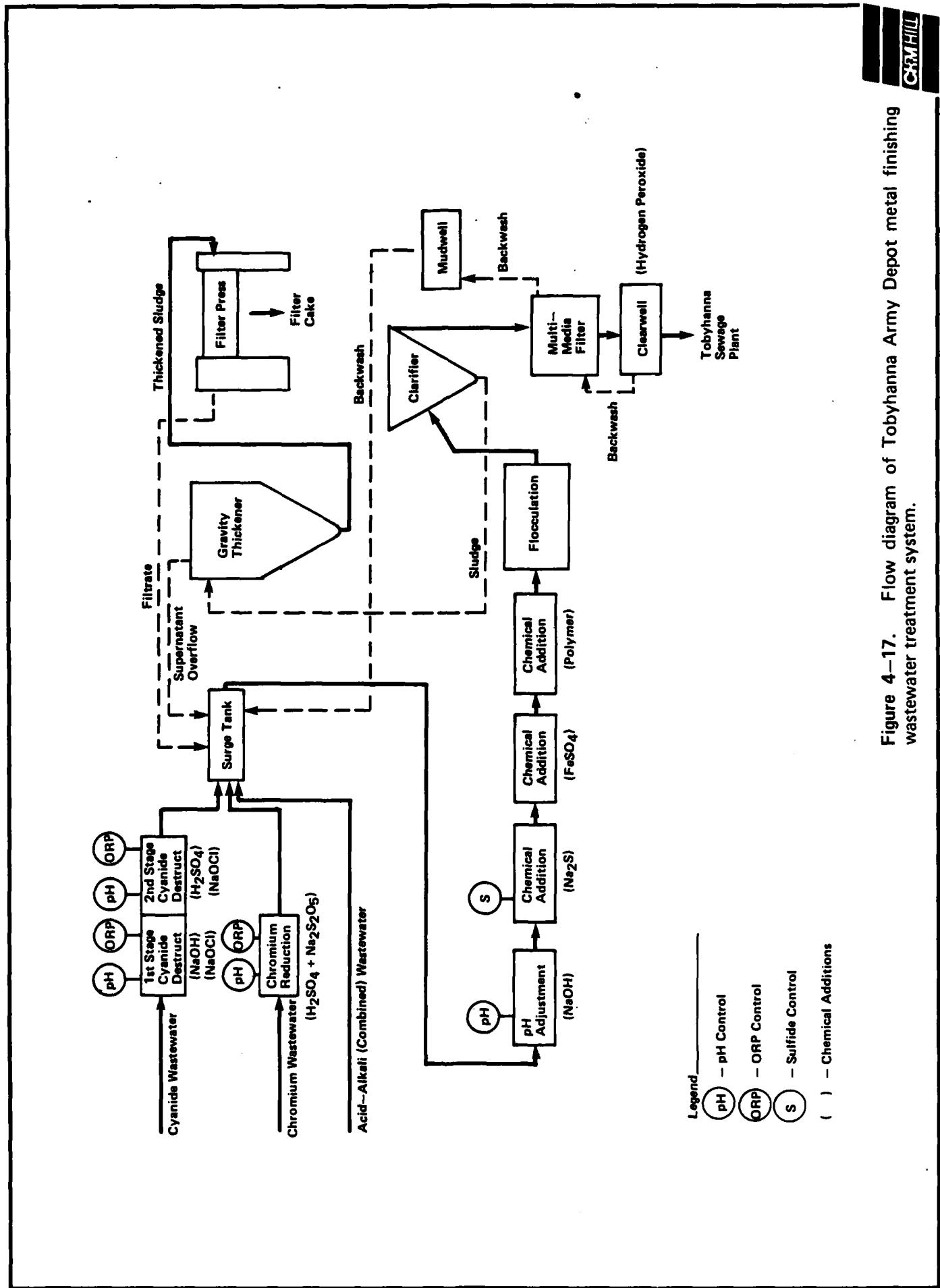


Figure 4-17. Flow diagram of Tobyhanna Army Depot metal finishing wastewater treatment system.

Table 4-7
TOBYHANNA ARMY DEPOT
WASTE AND TREATED EFFLUENT ANALYSIS (mg/L)

Parameter	Waste	Effluent		Daily Max		Daily Avg	
	Avg	Avg	Max	Design	Permit	Design	Permit
Cadmium	1.34	0.09	0.25	1.2	0.69	0.5	0.26
Chromium	1.14	0.31	1.15	7	2.77	2.5	1.71
Copper	2.35	0.07	0.47	4.5	3.38	1.8	2.07
Lead	0.43	<0.19	0.4	0.6	0.69	0.3	0.43
Nickel	1.61	0.08	0.35	4.1	3.98	1.8	2.38
Silver	-	<0.01	0.02	-	0.43	-	0.24
Zinc	3.4	0.37	2.69*	4.2	2.61	1.8	1.48
Cyanide	1.08	<0.04	0.12	0.8	1.2	0.23	0.65
Aluminum	6.67	4.3	18	1	-	0.5	-
Tin	0.003	<0.01	<1.0	2.5	-	1	-
Suspended Solids	-	18.8	152*	-	60	-	31
Oil and Grease	-	12.8	22	-	52	-	26

Dash indicates data not available or no standard specified.

*Exceeds permit limit.

Table 4-8 is a summary of the cost to install this 850-square-foot facility in 1981. The treatment chemical and sludge disposal costs averaged \$1.38 per thousand gallons treated during an 11-month period. During this period, an average of 395,000 gallons of wastewater was treated per month, at monthly costs of \$354 for treatment chemicals and \$191 for disposal of 175 gallons of sludge. Chemicals utilized include sodium metabisulfite, sodium hydroxide, sodium hypochlorite, sulfuric acid, ferrous sulfate, sodium sulfide, polymer, and hydrogen peroxide. Sludge disposal costs were based on \$60 per 55-gallon drum (32).

Table 4-8
TREATMENT PLANT INSTALLATION COSTS

Item	Cost (\$)
Cyanide Treatment	\$30,000
Chromium Treatment	\$25,000
Solids Separation	\$45,000
Sludge Dewatering	\$20,000
Support Equipment and Labor	\$152,000
TOTAL INSTALLED COST	\$272,000

While the pretreatment plant has sufficiently treated the wastewater it receives, currently 75 percent (31 gpm) of the flow from the plating shops bypasses the pretreatment facility and is discharged directly to the sanitary wastewater treatment plant.

Wastewater is discharged to the pretreatment facility from three sumps located in the plating shop: one containing cyanide wastes; one containing chromium wastes; and a third containing acid and alkali wastes. Table 4-9 lists the current flows and the flows on which the pretreatment facility design was based for each of the three sumps.

Table 4-9
PLATING WASTEWATER FLOW DATA (GPM)

Location	Design		Present	
	Total	Bypassed	Treated	Total
Cyanide Sump	8	0	11	11
Chrome Sump	4	4	5	9
Acid/Alkali Sump	<u>25</u>	<u>27</u>	<u>0</u>	<u>27</u>
TOTAL FLOWS	37	31	16	47

The significant bypass of almost two-thirds of the flow is due to two factors: since going into operation, wastewater flows from the plating shop have increased significantly, and the solids removal processes of the treatment plant have not been capable of operation at their design capacities.

The pretreatment system was designed to treat a combined waste flow from the plating and circuit board shops of 37 gpm. In conjunction with construction of the pretreatment facility, flow limiting and monitoring devices were installed on rinsewater tanks in the plating shop. Following their installation, flow from the plating shop was reduced to about 21 gpm. These flow reducing efforts, however, were not continued, and flow from the plating shop increased to 47 gpm, far in excess of the capacity of the pretreatment system. As a result, the acid and alkali and printed circuit board wastes were diverted directly to the sanitary sewer without pretreatment.

A controversy exists between the plating shop personnel and the pretreatment plant personnel over the necessity for the amount of water being generated by the plating shop. Plating shop personnel have expressed the opinion that the present flow is necessary to maintain good product quality,

while pretreatment plant personnel have contended that the flow can be reduced without compromising product quality. Metal concentrations in the waste are considerably lower than typical for efficiently operated countercurrent rinsing.

The pretreatment system capacity has been reduced from its design flow rating due to two problems: the filter is backwashed during periods of high waste flow, and the clarifier has not produced as concentrated a sludge as expected.

Filter backwash water is returned to the beginning of the plant (Figure 4-10) for treatment. Backwashing was intended to occur on an off shift when the plating facilities were not operating. Since the pretreatment plant is operated concurrently with the plating shop, the filter is backwashed during normal operations, significantly increasing the instantaneous flow requiring treatment.

The clarifier efficiency is adversely affected by a frequent on/off cycling of the sludge withdrawal pumps. This has resulted in a sludge solids concentration of 0.1 percent going to the gravity thickener rather than the 1 percent used for the design. The resulting supernatant flow from the gravity thickener to the surge tank is therefore much higher than design.

To reduce the loading on the treatment plant, there are plans to install 6,000-gallon and 20,000-gallon equalization tanks for chromium and acid/alkali wastes, respectively, around August 1985. Treatment plant personnel have noted that it will still be necessary to reduce water usage in the plating shops, since the pretreatment plant is operated only one shift per day, concurrently with the plating shop. The new equalization tanks will have approximately 11 hours of retention time at the current flows. This extra storage capacity could be used to store waste for treatment during a second shift. While it would be less expensive to reduce water consumption in the plating shop, this option deserves further evaluation.

In addition to hydraulic capacity problems, the pretreatment plant has been plagued by operational and maintenance problems. The O&M manual was inadequate, inaccurate, poorly organized, and virtually illegible. Operator training by the equipment vendor was rated as inadequate. The system was crowded into an extremely limited space, such that some anticipated repair procedures require moving the entire pretreatment unit to provide access.

During the initial visit to this facility during Phase 1, the project team was informed that the chromium waste reduction tank had sprung a leak and was being bypassed. The

operators noted that the O&M manual advised that ferrous addition in the main treatment system would be sufficient for chromium reduction as well as coagulation. The plant was reported to be meeting its chromium effluent limitations by this alternate treatment scheme. A new plastic tank was on order to replace the failed lined steel tank.

The treatment system was designed to segregate and treat cyanide wastes by two-stage alkaline chlorination. This system was in operation. Since installation of the system, the plating shop had converted to non-cyanide plating baths. Continued operation of the cyanide treatment system is of questionable benefit.

Future Direction

While the pretreatment facility is generally adequate, there are several deficiencies in the layout and operation and other problems resulting from a lack of cooperation between plating and treatment personnel.

The pretreatment facility is located in cramped quarters and has insufficient documentation for operation and maintenance. Location of the process did not allow for sufficient access for maintenance. This is particularly a problem at Tobyhanna, where little redundancy was incorporated in the design. Operation and maintenance are further hampered by the poor O&M manual, which also makes it difficult to train new employees.

The current disagreement between plating and pretreatment plant personnel could adversely affect both operations. It is imperative that the two work together to limit waste flows to the pretreatment facility without adversely affecting plating quality.

It would be of benefit to determine if the separate treatment of chromium and "cyanide" wastes is still necessary. Elimination of these processes would simplify the pretreatment system and eliminate the need for some chemicals. The effectiveness of alkaline chromium reduction using ferrous iron and sulfide has been demonstrated in the literature and in actual practice at the facility. Additional studies could verify this before permanently implementing this change.

4.5 Plating Recommendations

The constituents primarily responsible for complicating the treatment of wastewaters and increasing the production of hazardous waste from DOD plating operations are the result of chromium and cadmium electroplating. The principal sources of hazardous waste from these plating operations are drag-out to rinsewater and disposal of process baths. For these reasons, reduction of rinsewater and plating bath

dumping from chromium and cadmium plating would probably have the most impact on hazardous waste production from DOD plating operations.

Chromium is most often plated from a hexavalent chromium plating bath, which must be chemically reduced, often at an acidic pH, to the trivalent form so that it can be removed with other toxic metals by precipitation. Cadmium is usually plated from a cyanide bath. This cyanide requires separate treatment, typically being destroyed by alkaline chlorination. Cadmium itself is extremely toxic, and its presence in a waste, even in a low concentration, is usually sufficient to have the waste classified as hazardous.

Most chromium plating at DOD facilities is for remanufacturing of worn parts. This hard chrome plating produces a low volume of drag-out, compared with that produced by decorative or protective chromium plating operations. Technically complicated, capital-intensive processes for recovering chromium from this rinsewater (i.e., LICON system at Charleston NSY and Pensacola NARF) are not viable. Simpler methods of reducing rinsewater flow and increasing evaporation from the plating bath have proved sufficient to produce a zero discharge chromium plating system (Pensacola NARF). Cleanup of chromium plating baths has reduced the need to dispose of these baths. For these reasons it is recommended that the zero discharge hard chrome plating system as developed at Pensacola NARF be considered for adoption as the standard method for hard chromium plating in the armed services. Since parts that are first nickel plated cannot be plated by this new process, the requirement of nickel plating should be carefully evaluated to determine if it can be eliminated. Wide application of the zero discharge system to other metal plating operations should be actively pursued.

Good housekeeping practices and bath cleanup and maintenance can also eliminate the need for disposal of plating baths, as exemplified by the well operated plating facility at Anniston Army Depot, where only one plating bath has been dumped in 27 years of operation.

Materials substitution has proven effective at reducing the waste disposal problems associated with cadmium plating. Conversion to non-cyanide cadmium plating has been shown to be effective at Lockheed-Georgia Company, reducing the complexity of waste treatment without adversely affecting product quality. Vacuum deposition of cadmium (North Island NARF) is another method that eliminates use of cyanide and plating bath and rinsewater discharges, although still retaining some of the hazards associated with cadmium. Ion vapor deposition of aluminum (North Island NARF) offers the prospect of eliminating the need for cadmium coatings entirely. However, the capability of DOD plating facilities

to operate and maintain this complex equipment remains to be demonstrated. Due to the significant potential environmental advantages of IVD of aluminum, this method should be further studied, to determine if improvements can be made in how the system is used at North Island NARF. For parts still requiring cadmium plating, non-cyanide baths should be used where feasible.

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WDR111/021

Vehicle Washracks

5. VEHICLE WASHRACKS

5.1 Process Description

Vehicle washing is an important daily Army activity. All tracked and wheeled vehicles must be kept clean to increase the useful life of the equipment and allow proper inspection and maintenance. During field operations, vehicles can accumulate significant amounts of exterior and interior soil. For example, in certain areas of the country, tanks can accumulate up to one ton of exterior soil during a normal field maneuver. Interior soiling also occurs which can affect the accuracy of the sensitive instruments contained in the vehicle. In order to provide proper maintenance, interior and exterior cleaning must be performed.

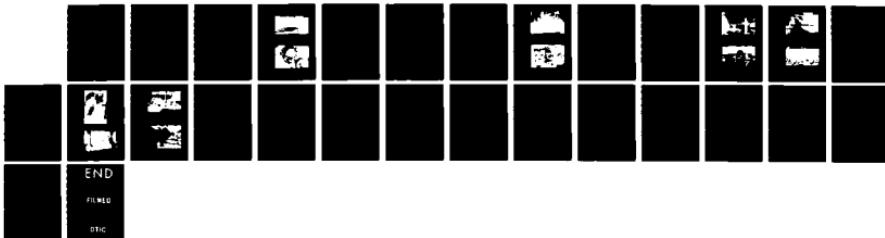
Cleaning to remove exterior soil from both tracked and wheeled vehicles is typically conducted at the end of training exercises, after road testing a serviced vehicle, and before inspections. Except for fuel transport vehicles, the cargo areas of vehicles are cleaned during exterior cleaning as well. Exterior cleaning is accomplished using a number of methods which include "bird baths" (large vehicle-sized bath tubs) and manual or automatic spray booths. The method selected for cleaning is dependent on the types of soil encountered during field activities, the amount of soil collected during these activities, and the amount of energy needed to remove the soils.

Interior vehicle cleaning often requires a different technique than is used for exterior cleaning because of the sensitive, sophisticated electronic, mechanical, and optical equipment housed in the vehicle (1).

Maintenance cleaning is performed on virtually all Army vehicles. Engine compartments are routinely cleaned before scheduled maintenance, unscheduled repairs, daily maintenance, and regular inspections. Maintenance cleaning is conducted at approximately 3,000 maintenance shops and 2,000 washracks in the continental United States and overseas (2). Maintenance cleaning is conducted to remove large amounts of oil, grease, and dirt from major mechanical and protective components including engines, hydraulic equipment, and transmissions.

Scheduled maintenance is primarily preventive in nature. It involves cleaning and inspecting vehicle components, greasing, oiling, changing lubricant, cleaning and replacing filters, and testing. Scheduled maintenance is the major activity within a motor pool area. Engine cleaning and petroleum, oil, and lubricant (POL) transfer are the major sources of pollution during scheduled maintenance cleaning.

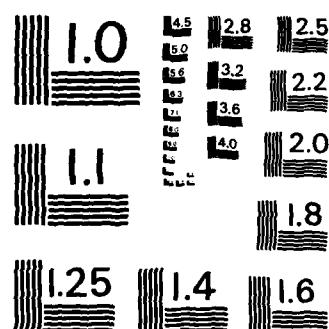
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Unscheduled maintenance is conducted primarily to correct acute or chronic vehicle component failures. Daily maintenance is primarily preventive, involving activities such as inspecting belt tensions and checking fluid levels.

5.2 Magnitude of the Problem

At most Army bases, cleaning and maintenance activities are combined in the same area (e.g., vehicle washrack, vehicle grease rack, or the hardstand area). As a result, the entire area becomes a source of pollution. These equipment maintenance facilities are designed such that all wet maintenance operations (e.g., oil changing and equipment cleaning) are performed in surroundings which make effective pollution control difficult and expensive (3). In many cases, newly designed facilities are a reflection of old facility designs which do not include new and used oil transfer and storage or proper wastewater treatment facilities.

Sources of wastewater from maintenance operations include the following:

1. Vehicle and equipment cleaning
2. Heavy maintenance cleaning (engine and engine compartment cleaning)
3. Oil changing and lubricant application
4. Improper handling and storage of new and used POL
5. Small parts cleaning
6. Radiator flushing
7. Vehicle and equipment parking

The quantity of wastewater generated at each facility will vary; however, those facilities having a greater number of vehicles are expected to generate a greater amount of wastewater.

Exterior and interior vehicle cleaning activities generally result in wastewater which contains primarily soil, water, and small quantities of oil (unless solvents or other cleaners are used). This wastewater is manageable by itself; however, when combined with wastes generated from maintenance cleaning activities, wastewater treatment and disposal problems become significantly magnified.

At older facilities, high volume, low pressure cold water cleaning systems are typically used for maintenance cleaning. Because this type of system is ineffective in removing most oily materials, solvents, detergents, and other cleaners are often used in combination with the water.

This method of cleaning results in a complex wastewater which is difficult and expensive to treat. Wastewater

treatment at these facilities generally consists of a gravity oil separator which is ineffective in removing emulsified oil and solvent contaminants. The wastewater generated at the combined facilities can result in NPDES permit violations if discharged directly to a receiving stream or operational problems if discharged directly to the installation's wastewater treatment plant.

Since these activities are often conducted at the washrake or hardstand area, the amount of wastewater (including stormwater) generated is large. Installation of a pretreatment system would be impractical unless the existing maintenance area can be modified to reduce the amount of wastewater generated.

Water used for vehicle cleaning represents a major percentage of the total water used at most installations. In many locations (e.g., the desert Southwest), water supplies are limited, sometimes severely. Methods for reducing the amount of water needed for vehicle cleaning and alternatives for reuse are necessary.

In several cases, new central vehicle wash facilities (CVWF) have been constructed which do not work properly (e.g., Ft. Riley, Ft. Carson, and Ft. Knox). Due to the soiling conditions present in the area, the wash facilities constructed could not adequately clean the vehicles. Automatic spray systems were provided for primary cleaning in places where bird bath facilities were required. Spray booths were provided for wheeled vehicles but did not work due to electronic equipment malfunctions and the odd shapes and sizes of some of the wheeled vehicles. Both the water pressure and volume provided to clean the vehicles were inadequate.

Filling and draining of cleaning facilities could not be accomplished in a reasonable length of time due to improperly sized pumping equipment. Ingress to and egress from the primary cleaning facilities (drive-through baths) were difficult, if not impossible. Vehicle cleaning times were excessive and resulted in inadequate cleaning. Oil/water and grit separation facilities were not designed to allow proper cleaning, and industrial wastewater was used for washwater makeup without proper removal of contaminants. Front-end loaders could not enter and exit the separator to remove grit.

Figures 5-1 and 5-2 show a typical tracked vehicle.



Figure 5–1. Tracked vehicle during field maneuvers.

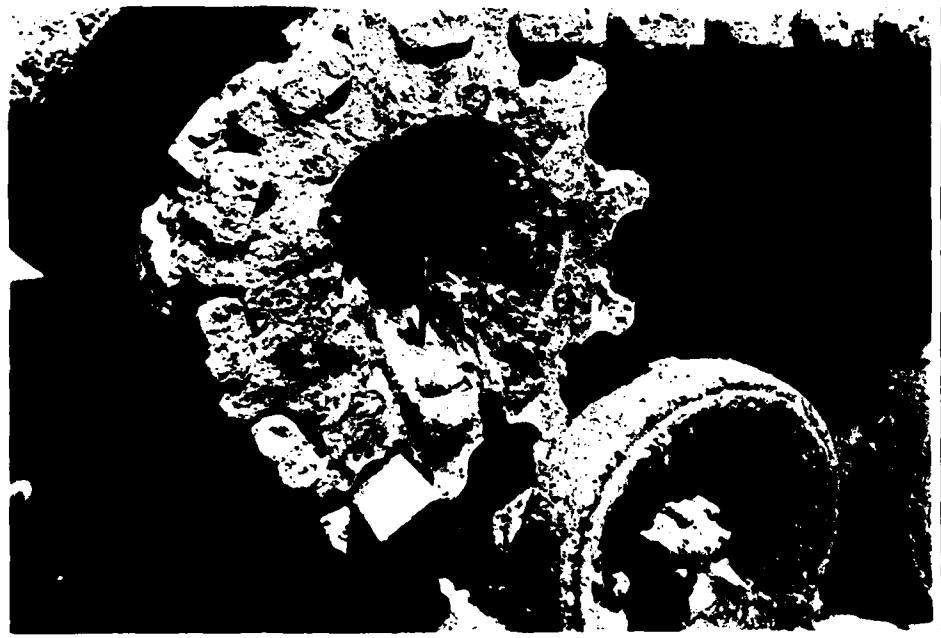


Figure 5–2. Tracked vehicles can accumulate up to a ton of soil during field activity.

5.3 Technologies Available to Reduce Hazardous Wastes from Washrack Operations

The ultimate purpose of vehicle washing and maintenance facilities is to provide an environment to Army personnel which is conducive to proper vehicle cleaning and maintenance. Because soiling conditions and equipment requirements vary from facility to facility, there is no single "correct" design or layout. However, there are some general modifications which could be applied to reduce the generation of wastewater containing hazardous contaminants.

The modification showing the most promise for significant results is to physically separate vehicle washing facilities from maintenance cleaning facilities. This modification segregates the two types of wastewaters generated, which are significantly different in character and treatment requirements. Separating the washing operations from the maintenance operations results in the following advantages:

1. Wastewater at both locations that can be easily treated using conventional methods
2. Increased waste oil collection
3. Decreased solvent and detergent usage
4. Improved maintenance and exterior cleaning efficiency
5. Lower water usage for vehicle washing due to direct water reuse
6. Reduced operation and maintenance (O&M) cost, since stormwater treatment is not required
7. Fewer troop manhours for cleaning

Existing vehicle washracks could be abandoned and replaced with one or two CVWFs per Army base. The facilities should be designed to reduce stormwater flow from the area. CVWFs also require that only one or two wastewater treatment systems be built instead of many. In short, CVWFs centralize wastewater treatment, reduce the quantity of wastewater generated, generate a wastewater treatable by conventional methods, increase the chances of spotting maintenance problems, and reduce capital and O&M costs. New modern facilities can also help induce military personnel to make proper use of the facility.

New CVWFs should include the following features:

1. Separate wash facilities for tracked and wheeled equipment
2. Improved washing equipment for tracked and wheeled vehicles
3. Effective wastewater treatment systems which allow either direct discharge to a surface-water body or direct recycle (e.g., settling, flow equalization, intermittent sand filtration, filtered effluent storage) (4)
4. Proper cleaning facilities and equipment for the types of soiling conditions expected (e.g., no "bird bath" facilities in areas where light soiling conditions exist)

Initiating these modifications can significantly reduce the quantity of wastewater generated while still allowing vehicles to be cleaned in an acceptable amount of time. The resulting wastewater can be treated using conventional methods to meet the discharge standards presented in Table 5-1. This method of treatment also allows treated water to be recycled back to the wash facility.

Table 5-1
EFFLUENT QUALITY CRITERIA (3)

Parameter	Concentration
Total Suspended Solids (mg/L)	300 maximum 200 average
Total Oil and Grease (mg/L)	100 maximum 50 average
pH (units)	6-9
BOD ₅ (mg/L)	400 maximum 300 average

Note: Effluent shall not contain any visible sheen; effluent shall be compatible with and not interfere with an installation's domestic wastewater treatment processes.

Historically, maintenance facilities have been on or adjacent to the hardstand and washrack areas. Because of the large surface area involved and widespread pollution,

contaminated stormwater treatment has become a major challenge. Scheduled maintenance activities, therefore, should be conducted in either retrofit facilities (upgraded existing motor pool areas) or new maintenance facilities. The upgraded or new facilities should be designed for high maintenance efficiency, pollution control, and spill containment. To prevent stormwater problems, the service area should be elevated. In addition, the service area should be divided into a dry oil changing area and a wet maintenance cleaning area. Waste oil can then be collected in the oil changing area and stored for separate recycling or disposal.

In the maintenance cleaning area, the engine packs can be cleaned. Hot water cleaning equipment, instead of steam or cold water with solvents, detergents, and other cleaners, can be used for maintenance cleaning. High pressure, low volume hot water cleaning without chemicals has been found to be more effective than cold water cleaning or steam cleaning in combination with chemical cleaners; in addition, it generates a smaller volume of wastewater, which can be treated using conventional treatment technologies. The recommended operating criteria for hot water cleaning equipment include 800 pounds per square inch (psi) operating pressure, 130°F operating temperature, and a 25 degree nozzle-spray pattern with a flow rate of 3.5 gpm (3).

Figures 5-3 and 5-4 show portions of an M-60 tank before and during cleaning operations.

5.4 Vehicle Washrack Case Studies

5.4.1 Vehicle Washrack at Ft. Polk, Louisiana

Ft. Polk Army Base in Leesville, Louisiana, constructed two new CVWFs in 1982. The base has recently completed construction of four new scheduled maintenance facilities and 12 more are under construction.

Prior to construction of the new CVWFs, individual washracks with potable water were heavily used for cleaning. The production rate at the existing washracks was 3.5 hours for 12 people to clean 6 tracked vehicles. Due to the high concentration of solvents, sediment, and oil in the wastewater from the washracks and the turbulence created during the cleaning operation, an emulsified, frothy waste, referred to at Ft. Polk as "chocolate mousse," was formed and required proper disposal. This frothy waste was not a defined hazardous waste according to standard testing (e.g., ignitability, reactivity, corrosivity, and EP toxicity); however, some solvent contamination was present. The frothy waste contained 20 to 75 percent water, which made solvent recovery economically infeasible. Commercial disposal of

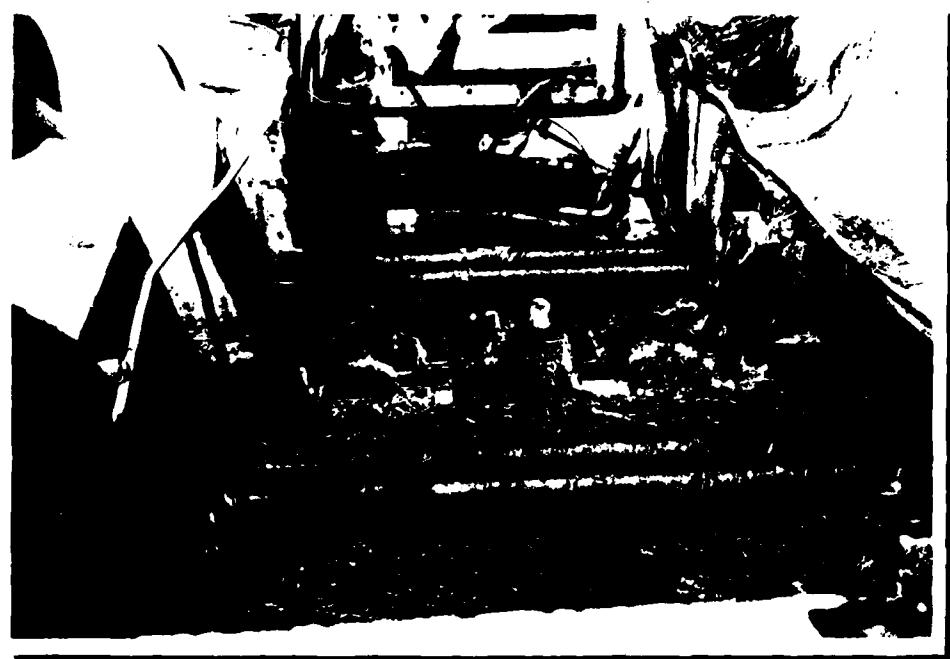


Figure 5-3. Oily engine compartment of an M-60 tank.



Figure 5-4. Conventional open area solvent and detergent cleaning of M-60 tank engine pack.

this waste product was estimated to be \$0.80 per gallon F.O.B. the disposal site. Approximately 15,000 cubic feet of the frothy waste were generated annually. This resulted in a disposal cost of \$84,000 per year (15,000 cf/y x 7 gallon/cf x \$0.80/gallon = \$84,000/year) plus transportation costs.

The new CVWFs each have three lanes and were designed specifically for exterior cleaning of tracked vehicles. These facilities use nonpotable water as a water source. The production rate for these new facilities is one hour for 12 people to clean 25 tracked vehicles. Six steps are required to initiate the process and one to terminate it. A 5-minute safety briefing is provided daily for each wash customer.

Large washing basins, referred to as "bird baths," were installed as part of the CVWF to help remove heavy soil which accumulates within the tracks and on the underside of the vehicles. The bird bath is filled with water and the vehicles drive through for the primary washing action.

Twenty-inch diameter pipes have been filled with concrete and partially submerged in the bottom of the basin. Two rows of staggered pipes have been installed for each lane, causing a teetering action when a tank or other tracked vehicle drives through the bird bath. The tracks move through their entire range of motion as they proceed over the corrugations on the bottom of the bird bath, dislodging any caked-on soil.

Water monitors (spray cannons) deliver water at 360 gpm and 40 psig pressure at the vehicles above the water level in the bird bath to provide secondary cleaning.

Washrack facilities with hoses are provided to clean the inside of vehicles after they exit the bird bath. One lane at each CVWF has been modified by inserting concrete parking curbs between corrugations to enable use by wheeled vehicles.

Waste washwater is discharged to a sedimentation lagoon for suspended solids removal and reuse. No oil sheen has appeared on the basin in 3 years of operation. On an annual basis, evaporation from the lagoon is approximately equal to the precipitation plus stormwater runoff, which recharges the lagoon. Consequently, little makeup water is required.

It is estimated that the approximately 20,00-30,000 cubic yards of sediment produced each year will be removed by dredging every 4 to 5 years. The sediments have been tested for heavy metals and EP toxicity and are not defined as being hazardous. The ponds have been stocked with fish, on which bioassays will be performed in the future.

Even though operation is continual, Ft. Polk has had few problems with their wash and recycle system during 3 years of operation. The CVWF has operated 24 hours per day 7 days per week for 3 years with no disruptions. Compared to previous vehicle washracks, the new wash facilities result in cleaner vehicles, allowing for improved operator maintenance and better maintenance inspection. The only maintenance problem noted was with the four buried butterfly valves used to control discharge into the bird baths. Higher quality water monitors would be preferred over the existing monitors to prevent erosion of seals and other components. One unanticipated problem was theft of the brass water monitor nozzles, presumably for their pawn shop value.

The research cost for designing the wash facilities at Ft. Polk was \$263,000. Costs for facility construction, energy, wastewater treatment/reuse facilities, and new trails to and from the facility amounted to \$4,994,000 (1982 dollars) (8).

Figures 5-5 through 5-8 show details of Ft. Polk wash facilities.

Until all of the new scheduled maintenance facilities are completed, servicing will continue as required at the individual washracks. Some solvent and oil control benefits have already been realized by removing the exterior wash function from the old washracks. The hazardous waste solvents and oil generated at the washracks are now recyclable and sold through DPDO for \$0.39 per gallon. The goal is to eventually reuse the material as a boiler fuel, replacing current fuel which costs over \$1.00 per gallon. Ft. Polk is collecting approximately 18,000 gallons of waste oils and solvents per year, which is expected to result in an annual savings of \$7,020.

Construction of the new CVWFs at Ft. Polk has resulted in the following significant benefits:

1. Annual labor requirements for vehicle cleaning have been reduced by 194.5 man-years.
2. Frothy waste disposal costs of \$84,000 per year have been reduced to essentially zero.
3. Oil- and solvent-containing wastes are now being recovered and sold to a recycler for \$0.39/gallon at an annual savings of \$7,000.
4. Approximately one-third as much water is needed for cleaning each vehicle.



Figure 5-5. Conventional vehicle wash facility at Fort Polk.



Figure 5-6. New "Bird Bath" central vehicle wash facility at Fort Polk.

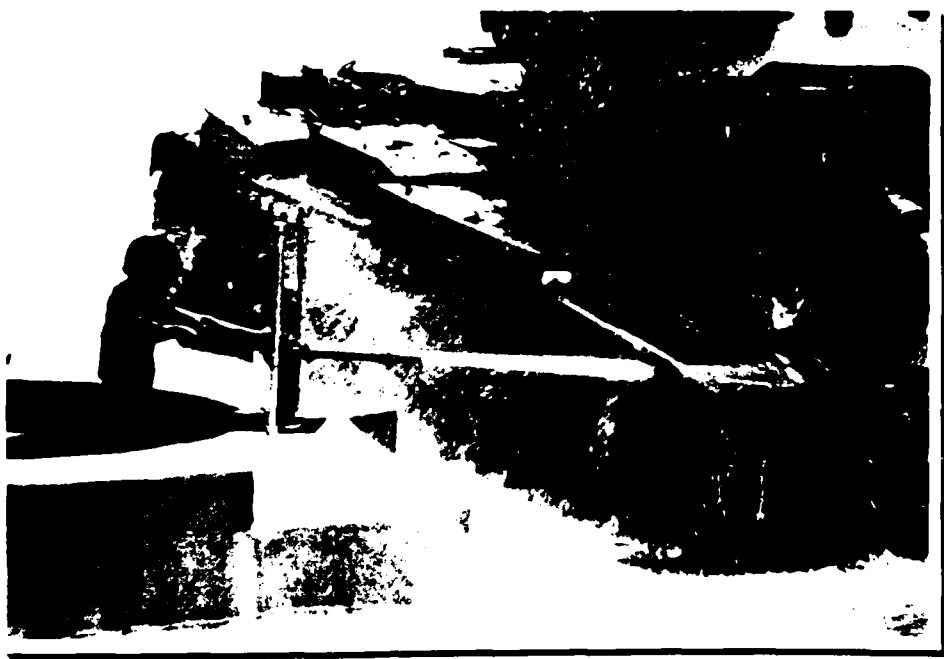


Figure 5-7. Water monitor helps to clean tank exterior at Fort Polk.

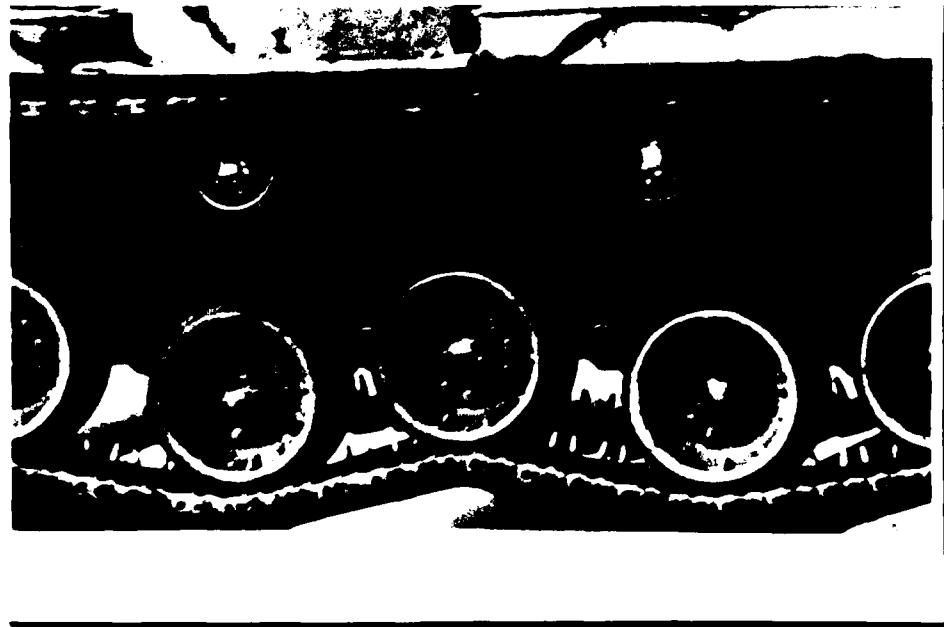


Figure 5-8. Staggered pipes for flexing treads (normally submerged) causes most of tread cleaning.

5. The water used for vehicle cleaning is recycled. Annual evaporation approximately equals precipitation plus stormwater runoff; therefore, little make-up water is required.
6. Since solvents and cleaners are no longer used, expensive pretreatment facilities are not needed.
7. O&M costs for central vehicle wash facilities are approximately 50 percent less than the corresponding costs for the older vehicle washracks.
8. Cleaner vehicles are produced by the new wash facilities, allowing better maintenance inspection and thus shorter service time.
9. Lower volumes of wastewater are generated which require smaller oil/water separation pretreatment facilities.
10. Hot high pressure water eliminates the need for solvents and cleaners.

The benefits for Ft. Polk as a result of the new combined vehicle wash facilities were estimated by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) to be \$10.4 million per year (8).

5.4.2 Vehicle Washrack at Ft. Lewis, Washington

Ft. Lewis, located in Tacoma, Washington, is the only Army installation which has implemented both CVWFs and scheduled maintenance facilities. There are three wash facilities at Ft. Lewis and one at the Yakima firing range, which is under Ft. Lewis supervision. There are 44 scheduled maintenance facilities at the base.

Ft. Lewis does not have bird baths. Because the Washington soils are lighter than Louisiana soils, the bird bath type of operation is not required for good cleaning. Ft. Lewis has installed a series of new washracks in each of the central facilities which consist of an overhead boom and hose to supply water at 30 gpm and a pressure of 90 psig. Each CVWF has separate lanes for tracks and wheeled vehicles.

Waste washwater is collected in a drain, then treated prior to recycling. Treatment processes include API oil/water separation, equalization, and intermittent sand filtration. The reclaimed washwater is pumped from the detention basin for reuse. The north Ft. Lewis facility does not recycle water, but instead discharges it directly to the sanitary sewer.

4. The process is easy to operate and involves adaptation of conventional technology.
5. From a production standpoint, manpower requirements are significantly reduced, product quality is improved, and production costs are significantly lower.

The zero discharge chromium plating system, developed at Pensacola NARF by the Naval Civil Engineering Laboratory (NCEL) at Port Hueneme, likewise combines the incentives of production improvement with reduced hazardous waste production. The process is also widely applicable. From a production standpoint, rejection rates are drastically reduced, plating rates are increased, and fewer plating baths are required to plate the same number of parts. In addition, frequency of plating bath dumps has been reduced and industrial wastewater treatment has been simplified.

The central vehicle washrack and vehicle maintenance facilities at Fort Lewis, Washington are recommended principally for their segregation of exterior vehicle washing from vehicle maintenance and engine compartment cleaning. Conventional cleaning with cold water, solvents, and detergents on open pads resulted in a significant contamination of stormwater. The modification uses off-the-shelf high pressure hot water cleaning equipment for engine compartment cleaning, eliminating the use of solvents and greatly reducing the volume of waste requiring treatment. The overall system has also greatly reduced the manpower requirements for vehicle cleaning. Significant cost savings are projected compared to the previous operation.

6.3.2 General Recommendations

Based on our analysis of the 40 cases in this study, the following recommendations are submitted. This list of 12 general recommendations is designed to supplement the process-specific recommendations at the end of Chapters 3, 4, and 5.

1. Identify the potential advantages and disadvantages of including the costs of hazardous waste disposal in production budgets so that they will be used in production decisions.
2. Investigate the possibility of providing incentives for hazardous waste reduction efforts (e.g., returning money not spent on disposal to the base recreation and welfare fund).

TABLE 6-1 EVALUATION OF CASE STUDIES

REPORT SECTION	FACILITY, MODIFICATION	STUDY VALUE					STUDY					APPLICATION SUCCESS					SUCCESS			TOTAL SCORE
		A	B	C	D	E	SCORE	F	G	H	I	J	K	L	M	N	O	SCORE		
3.4.1	HILL AFB, DRY PAINT STRIPPING	1.0	1.0	1.0	1.0	1.0	100	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.5	19.5
4.4.3	PENSACOLA NARF, SPRAY RINSE	1.0	1.0	1.0	1.0	1.0	100	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.5	19.5
5.4.2	FORT LEWIS ARMY, VEHICLE WASHRACKS	1.0	1.0	1.0	0.5	1.0	90	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.5	18.5
3.4.6	ROBINS AFB, SOLVENT RECYCLE	1.0	1.0	1.0	1.0	1.0	100	0.5	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	8.0	18.0
3.4.2	PENSACOLA NARF, DRY PAINT STRIPPING	0.7	1.0	1.0	1.0	1.0	94	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	8.5	17.9
5.4.1	FORT POLK ARMY, VEHICLE WASHRACKS	0.7	1.0	1.0	0.5	1.0	84	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.0	17.4
3.4.7	NORFOLK NSY, SOLVENT RECYCLE	1.0	0.5	1.0	1.0	1.0	90	0.5	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	7.5	16.5
4.4.5	ANNISTON ARMY DEPOT, PLATING	0.7	1.0	0.7	1.0	1.0	88	0.5	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.0	15.8
3.4.3	PENSACOLA NARF, WATER PRIMER	1.0	0.5	0.7	1.0	1.0	84	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.0	15.4
3.4.5	HUGHES (USAF), POWDER COATING	1.0	0.5	0.5	1.0	1.0	80	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.0	15.0
4.4.2	LOCKHEED (USAF), Cd PLATING	1.0	0.5	0.7	1.0	1.0	84	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	6.5	14.9
3.4.10	ANNISTON ARMY DEPOT, SOLVENT RECYCLE	1.0	0.5	0.7	1.0	1.0	84	0.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	6.0	14.4
3.4.4	LOCKHEED (USAF), PAINTING	0.7	0.3	1.0	1.0	1.0	80	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	6.0	14.0
3.4.8	TYNDALL AFB, SOLVENT RECYCLE	0.7	1.0	1.0	1.0	1.0	94	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.0	13.4
4.4.6	TOBYHANNA ARMY DEPOT, WASTE TREATMENT	1.0	0.5	0.7	1.0	1.0	84	0.5	0.5	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	3.5	11.9
3.4.9	NORFOLK NARF, HEPTANE RECYCLE	1.0	0.7	0.7	1.0	1.0	88	0.5	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	2.5	11.3
4.4.1	NORTH ISLAND NARF, IVD OF ALUMINUM	1.0	0.7	0.7	1.0	0.7	82	0.5	0.5	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	2.5	10.7
4.4.4	CHARLESTON NSY, LIQUID CHROME RECOVERY	1.0	0.5	0.7	1.0	0.7	78	0.0	0.5	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	2.5	10.3

STUDY VALUE	WEIGHTING VALUE					TOTAL SCORE
	A	B	C	D	E	
A CONCRETE EXAMPLE	1.0	1.0	1.0	1.0	1.0	0.0
B WASTE REDUCTION	YES	MAJOR	MAJOR	MAJOR	YES	0.0
C WASTE GENERATION						0.0
D EPA HAZWASTE						0.0
E POTENTIAL USE						0.0
APPLICATION SUCCESS						0.0
F ENERGY USE	LOWER	LOWER	LOWER	LOWER	LOWER	HIGHER
G MANPOWER	LOWER	LOWER	LOWER	LOWER	LOWER	HIGHER
H MATERIAL COSTS	LOWER	LOWER	LOWER	LOWER	LOWER	HIGHER
I CAPITAL COSTS	EASY	MEDIUM	MEDIUM	MEDIUM	MEDIUM	HARD
J MAINTAINABILITY	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM	LOW
K RELIABILITY	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM	COMPLEX
L SIMPLICITY	SIMPLE	CHAMPION	CHAMPION	CHAMPION	CHAMPION	INDIFFERENT
M STAFF ENTHUSIASM	CHAMPION	SUPPORTIVE	SUPPORTIVE	SUPPORTIVE	SUPPORTIVE	INDIFFERENT
N MANAGEMENT	CHAMPION	FAVORABLE	FAVORABLE	FAVORABLE	FAVORABLE	NEGATIVE
O PRODUCT IMPACT	FAVORABLE	FAVORABLE	FAVORABLE	FAVORABLE	FAVORABLE	FAVORABLE

NOTE: Each modification was assigned a score for each of fifteen criteria. The criteria applied and the scores possible for each criterion are shown below. Five of the criteria are to determine the example value of the case, or potential for reducing hazardous waste, if successfully applied. Double the sum of these values is used to compute the "Study Score." The second ten criteria were used to evaluate the success of the modification and potential for successful application at other DOD facilities.

Staff Enthusiasm: Were operating personnel involved in the process change? Were they enthusiastic participants, actively working to make the process work?

Management: Did management provide the support (i.e. manpower slots) needed to make the process modification a success?

Product Impact: Did the process change have a favorable impact on product quality or reduce the time needed to perform the process?

These criteria were used to determine how successfully the process modifications had accomplished the goals of efficiently reducing the generation of hazardous waste and how likely they were to be effectively applied at similar installations. Scores of 0 to 1 were assigned to each of the cases based on how well they satisfied each of these criteria. These scores were then summed to obtain a "Success Score" between 0 and 10. The Study Scores and the Success Scores were added for each of the cases to obtain a composite score that was used for ranking the cases. The top three cases are recommended for selection as Projects of Excellence for employee briefing and training programs during Phase 3 of the project.

6.3 Recommendations

6.3.1 Recommendation of Projects of Excellence

The 18 cases studied in Phase 2 of the project were scored using the evaluation model. A ranked listing of the cases with their scoring is provided as Table 6-1. The three top-ranked cases are recommended to be selected as the three Projects of Excellence.

Plastic media paint stripping at Hill Air Force Base is recommended for the following reasons:

1. Widespread DOD adoption has the potential of reducing the costs of operation by at least \$100,000,000 per year, a significant internal incentive to production and management people to implement this change.
2. Adoption of the process would eliminate one of the major liquid hazardous waste sources in the armed services.
3. Its applicability is widespread, potentially applicable at every military installation.

Potential Use: How widely is the process used in the armed services? Would the process modification have widespread application?

Notice that the five criteria do not judge the success (or lack thereof) of a given modification. These criteria were used in Phase 1 to determine which cases would be most valuable for further study during Phase 2 of the project. Scores of 0 to 1 were assigned to each of the cases based on how well they satisfied each of these criteria. The sum of these values was then doubled to obtain a "Study Score" between 0 and 10.

The evaluation of whether or not a process modification was successful was separated from the determination of its value as an example. To determine if a modification was successfully applied, the project team evaluated whether or not the modification had been implemented as proposed, proved cost-effective, and was sustainable or capable of being carried on indefinitely. An assessment model was prepared to help evaluate cases for consideration as Projects of Excellence. This model evaluated cases according to the following ten criteria of success:

Energy Use: Did operation of the process modification result in a reduction in energy use at the facility?

Manpower: Did the modified process require fewer or less skilled personnel than existing operation?

Materials Costs: Did the process modification reduce the costs of raw materials used?

Capital Costs: How did the costs associated with purchase and installation of equipment used for the process modification compare with these costs for the process it modified?

Maintainability: Were the process changes and associated equipment easy to maintain?

Reliability: Did the equipment operate for reasonable periods without needing to be shut down for maintenance?

Simplicity: Was the modified process and associated equipment easy to operate? Were skilled operators required?

usefulness as an example of how processes can be implemented and how successfully each modification was applied.

Cases were favored in which modifications were seriously attempted, successfully applied, have a widespread application, and have the potential of producing a significant reduction in hazardous waste generation.

Rating criteria were developed based on several objectives. In the contract document, the Architect/Engineer (CH2M HILL) is directed to:

"... focus on a few processes which generate the greatest portion of DOD hazardous wastes, such as electroplating or paint stripping, under the premise that an in-depth study of these with an implementable action objective is more in line with the overall goal of environmental improvement than a cursory cataloging of a large number of DOD industrial processes for potential action only ..."

Therefore, the selection criteria chosen were those which favored process modifications that could have reduced large quantities of wastes at the facility investigated, and that were widely applicable to other DOD facilities.

An assessment model was prepared to help evaluate cases for consideration in Phase 2 of the project. This model evaluated cases according to the following five criteria:

Concrete Example: Was there a modification proposed, and is sufficient information available (i.e. existing operation, reports, conversations with personnel) to perform a detailed study of the modification?

Waste Reduction: To what extent would the proposed modification, if successful, effect a significant reduction in waste generation at the facility?

Waste Generation: At the average facility using the industrial process, how much waste is produced that would be affected by the proposed modification?

EPA Hazwaste: Would the affected waste be classified as a hazardous waste under EPA regulations? (For a detailed description of EPA hazardous waste regulations and definitions, see 40 CFR Part 261-- Identification and Listing of Hazardous Waste).

4. Support was provided at a sufficiently high level in the chain of command to influence production and environmental policy decisions. Frequently, waste disposal and environmental protection had been viewed as service functions, subservient to the mission of the facility, which was usually production-oriented. Successful modifications usually required the reallocation of resources from production functions to environmental protection. Allocation of manpower slots for environmental protection was particularly difficult to obtain.
5. The technologies tended to require "evolutionary" rather than "revolutionary" changes. That is, off-the-shelf equipment was adapted to a new application, and special or complex equipment was avoided.
6. Successful modifications were straightforward and simple to operate, thus requiring minimal training for personnel unfamiliar with the technology involved.
7. Process reliability had to be high so as not to adversely affect production. Maintenance requirements were minimal.
8. At facilities where modifications were successful, true costs of hazardous waste disposal were appreciated by management, and were considered in the decision to implement the modifications. At DOD facilities, the Defense Property Disposal Office (DPDO) takes hazardous waste, which must be disposed of off the installation, without charge. This has resulted in a disincentive to production people to reduce their generation of hazardous wastes, since costs of waste disposal are not charged to production activities. At some installations, industrial treatment facilities have been sized to handle the existing waste flow. This has resulted in a disincentive to reduce waste production.

6.2 Selection Criteria for Projects of Excellence

The prime objective of Phase 2 of this project, and consequently this report, is to recommend three cases as Projects of Excellence, to be showcased with employee briefing and training programs in Phase 3 of the project.

The 18 cases outlined in Chapters 3 through 5 of this report were evaluated. This evaluation was based on each case's

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Industrial modifications were generally found to be successful; however, some modifications failed and others could not be adequately evaluated.

While there are specific circumstances and reasons behind the success or lack of success of each modification attempted, two characteristics have been integral parts of each of the successful process modifications and at least one of these elements has been missing from the modifications that have been less than successful. Very simply stated, in process modifications that were successfully implemented, the end user was sufficiently motivated to make the change and the technologies were "elegant in their simplicity." Factors which have motivated personnel included improved production rate or quality, reduced overall costs, decreased manpower requirements, and decreased quantity of hazardous wastes to be disposed of. Technologies that were "elegant in their simplicity" were easy to operate and maintain, reliable, and cost effective. Successfully implemented process modifications combined effective technology and motivated personnel to significantly reduce hazardous waste production by substantially changing the process, substituting raw materials, or recovering and reusing waste by-products.

In general, a number of common features distinguished successful process modifications from those that were not. These features are outlined below:

1. Production people were enthusiastically and actively involved in implementing successful process modifications. This usually required that some incentive be offered by the modification, such as reduced manpower requirements or simplification of the process. The change could not harm product quality, and preferably was an improvement over existing processes.
2. A "champion," who strongly believed in the modification, ramrodded the project, and overcame developmental problems and the inertia that protects existing processes (especially those that function, although they may produce undesirable wastes).
3. Care was taken to tailor the modification to the individual facility. During design and installation, many operations personnel were included to obtain their input and to inspire them to adopt the process change.

**Conclusions and
Recommendations**

4. Vehicle maintenance cleaning should be conducted with high pressure, low volume hot water cleaning equipment capable of meeting the service requirements without using solvents and/or other cleaning aids (3).
5. Oil/water separators should be used to remove suspended solids and free oils (hydraulic overflow rate <100 gpd/ft² and hydraulic detention time of 8 hours) for pretreatment of wastewater discharged from improved track vehicle maintenance facilities which have high pressure, low volume hot water wash equipment incorporated into their design (3).
6. Waste oil handling methods should be provided which minimize manual handling (1).

5.6 Washrack References

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7. DRAFT--Overview of TOE Maintenance Activities and Pollution Control at Army Installations, Department of the Army, USCOE, Washington, D.C. 20314, February 28, 1983.
8. "Centralized Vehicle Washing and Vehicle Maintenance Facilities,"--DRAFT CERL, USCOE, February, 1985.

Table 5-2
 SUMMARY OF PROBLEMS AND RECOMMENDED SOLUTIONS
 FOR DESIGN, CONSTRUCTION, AND OPERATION
 OF CVWFs AND VEHICLE MAINTENANCE FACILITIES

Problem	Proposed Solution
1. Combined vehicle wash and maintenance facilities result in a large volume of wastewater which is difficult to treat collectively. Direct discharge results in NPDES permit violations, and discharge to treatment plants results in operational problems.	Separate the facilities.
2. Low pressure, cold water cleaning systems are inadequate. Solvents and other cleaners are required for proper cleaning. This results in a wastewater which is difficult and expensive to treat.	Replace existing water cleaning systems with high pressure low volume cleaning systems at the wash racks and high pressure, low volume, hot water cleaning systems at the maintenance facilities. Discontinue use of solvents and cleaners.
3. Water usage at existing vehicle washracks is high. In some areas, available water is limited.	Design the washing facilities to allow water reuse.
4. Contaminated stormwater results in a large volume of wastewater requiring treatment.	Design the systems to minimize stormwater contamination by diverting the stormwater away from the site.
5. Vehicle wash facilities have been designed and constructed which do not work adequately, so that vehicles are not properly cleaned and cleaning times are excessively long.	Design new facilities with site specific design requirements in mind. Refer to previously published design information. Consult with USA-CERL for further assistance.

3. High pressure hot water used for maintenance cleaning and supplied at 3.5 gpm has replaced low pressure cold water supplied at 30 gpm and high pressure steam. This has resulted in significant water savings and reduced maintenance requirements.
4. Since the total wastewater flow was reduced, smaller oil/water separation facilities were required. CERL estimates this to have resulted in a \$1.1 million savings in equipment alone (8).
5. Solvents, cleaners, and detergents are no longer required since high pressure hot water is used for maintenance cleaning and high pressure water is used for vehicle washing.
6. Oil recovery has increased from approximately 54,000 gallons per year to 90,000 gallons per year. This oil is sold to a recycler for \$0.30/gallon, resulting in an annual recovered cost of \$10,800 (8).
7. Cleaner vehicles allow better maintenance inspection and thus shorter service time.
8. O&M costs for the new facilities are approximately 50 percent of the corresponding costs for the old facilities.

5.5 Washrack Recommendations

Table 5-2 summarizes the problems encountered at existing vehicle wash and maintenance facilities and provides the latest recommended methods for minimizing or overcoming these problems. Additional recommendations are given below.

1. When planning CVWFs, special attention should be paid to design considerations (e.g., type of soil to be removed, cleaning frequency, number of vehicles). The facilities should be designed accordingly. A new wash facility should not be designed around another facility's operation without thorough research (5).
2. USA-CERL should be consulted concerning proper design of a CVWF. Their design guides should be followed where applicable (5).
3. All vehicle maintenance (tracked and wheeled) should be conducted at a vehicle maintenance facility which is separate from the wash facility to allow for more efficient maintenance operations. Separation of facilities allows greater control over the type and quantity of wastes generated and their ultimate method of disposal (3).



Figure 5-11. Covered scheduled maintenance facility at Fort Lewis.



Figure 5-12. Hot water cleaning of engine pack at Fort Lewis.



Figure 5-9. Central vehicle wash stands at Fort Lewis. (Two sets of stands in background, intermittent sand filters and water storage ponds in foreground.).



Figure 5-10. Exterior wash stands at Fort Lewis.

Two commercial vehicle wash facilities have been installed in conjunction with the central wash facilities. One services primarily cars and has operated well. The other serves irregularly shaped wheeled vehicles and has had numerous operating and maintenance problems.

With the lower pressure water in the old system, tracked vehicles required approximately 2 hours for proper cleaning. With the new high pressure system, a tracked vehicle can be washed in approximately 20 to 30 minutes and wheeled vehicle in 15 to 20 minutes.

The scheduled maintenance facilities are designed for the type and number of vehicles serviced presently. High pressure hot water is supplied for cleaning, thereby eliminating the need for solvents and detergents. Steam was used for cleaning purposes at the older washrack, resulting in maintenance and safety problems. However, the problems associated with the high temperatures of the steam have mostly been eliminated with the hot water system.

Figures 5-9 through 5-12 show washing and maintenance facilities at Fort Lewis.

Wastewater from combined washing and servicing operations had previously been discharged to the storm sewer. The waste contained large amounts of oil and solvents, which led to numerous violations of the discharge permits. In addition to separating exterior washing from service washing, oil separators have been installed on the storm drain discharges. The combination of reduced solvent use, better control of waste oil, and installation of oil/water separators has led to a 90 to 95 percent reduction in the contaminants being discharged to the surface water. Discharges are now regularly meeting NPDES discharge limitations.

The research and development cost for designing central vehicle wash facilities for Ft. Lewis was \$263,000. The cost to construct the facilities was \$3,645,000 (1981 dollars). The research and development cost for designing maintenance facilities was \$296,000. The cost to construct the facilities was \$7,545,000 (1981 dollars) (8).

Construction of the new central vehicle wash and maintenance facilities has resulted in the following significant benefits:

1. Man-hours needed for cleaning track vehicles have been reduced by 85 percent.
2. Expensive pretreatment facilities required to treat a wastewater consisting of oil, solvents, sediment, and detergents became unnecessary. CERL estimates this savings to be approximately \$5 million (8).

3. Include production people in the design effort; since they will be left to operate the modified process, they need to feel that it is theirs.
4. Ensure that environmental effects are considered as important as production when conflicts between the two arise. It may be desirable to make environmental rating one of the evaluation criteria for the base commander.
5. Ensure that adequate funding is provided to support wider adoption of proven process modifications.
6. Ensure that appropriate adaptations are made to all technologies (even off-the-shelf systems) before transferring them to facilities where they have not been tested; thus, each technology will be "tailored" to the individual facility.
7. In view of the typically high turnover rate among operations personnel, ensure that a sufficient number of personnel are trained to provide back-up operation when necessary.
8. Ensure that the data collected to predict costs and benefits of a particular technology are accurate, valid, and sufficient.
9. Ensure that design personnel devote sufficient time, after equipment installation, to inspecting the system for proper operation and maintenance.
10. In considering locations for future demonstration studies, select only facilities where the responsible personnel are enthusiastic about the study.
11. In conducting future demonstration studies, ensure that sufficient manpower is assigned and that the personnel are adequately trained, well supervised, and not fully committed to other projects.
12. Whenever possible, make adaptations to off-the-shelf equipment with a proven record of reliability rather than selecting specialized or complicated equipment.

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